PB87-234522

# Prevention Reference Manual: Chemical Specific. Volume 7. Control of Accidental Releases of Chloropicrin (SCAQMD) (South Coast Air Quality Management District)

Radian Corp., Austin, TX

Prepared for

Environmental Protection Agency
Research Triangle Park, NC

Aug 87

U.S. Department of Commerce
National Technical Information Service
NTIS

PB87-234522

EPA/600/8-87/034g
August 1987

# PREVENTION REFERENCE MANUAL:
# CHEMICAL SPECIFIC
# VOLUME 7: CONTROL OF ACCIDENTAL RELEASES OF CHLOROPICRIN (SCAQMD)

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Contract No. 68-02-3889
Task No. 98

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RESEARCH TRIANGLE PARK, NC 27711

**TECHNICAL REPORT DATA**
*(Please read Instructions on the reverse before completing)*

| 1. REPORT NO. | 2. | 3. RECIPIENT'S ACCESSION NO. |
|---|---|---|
| EPA/600/8-87/034g | | PB87-234522/AS |

| 4. TITLE AND SUBTITLE | 5. REPORT DATE |
|---|---|
| Prevention Reference Manual: Chemical Specific, Volume 7: Control of Accidental Releases of Chloropicrin (SCAQMD) | August 1987 |
| | 6. PERFORMING ORGANIZATION CODE |
| 7. AUTHOR(S) | 8. PERFORMING ORGANIZATION REPORT NO. |
| D. S. Davis, G. B. DeWolf, and J. D. Quass | DCN 87-203-024-98-26 |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS | 10. PROGRAM ELEMENT NO. |
| Radian Corporation<br>8501 Mo-Pac Boulevard<br>Austin, Texas 78766 | 11. CONTRACT/GRANT NO.<br>68-02-3889, Task 98 |
| 12. SPONSORING AGENCY NAME AND ADDRESS | 13. TYPE OF REPORT AND PERIOD COVERED |
| EPA, Office of Research and Development<br>Air and Energy Engineering Research Laboratory<br>Research Triangle Park, NC 27711 | Task Final; 9/86 - 4/87<br>14. SPONSORING AGENCY CODE<br>EPA/600/13 |

15. SUPPLEMENTARY NOTES AEERL project officer is T. Kelly Janes, Mail Drop 62B, 919/541-2852.

16. ABSTRACT The manual summarizes technical information that will assist in identifying and controlling chloropicrin-associated release hazards specific to the South Coast Air Quality Management District (SCAQMD) of southern California. The SCAQMD has been considering a strategy for reducing the risk of a major accidental air release of toxic chemicals. The strategy includes monitoring the storage, handling, and use of certain chemicals and providing guidance to industry and communities. Chloropicrin has an immediately dangerous to life and health (IDLH) concentration of 1 ppm, making it a substantial acute toxic hazard. To reduce the risks associated with an accidental release of chloropicrin, some of the potential causes of accidental releases that apply to processes that use chloropicrin in the SCAQMD must be identified. Examples of potential causes are identified, as are measures that may be taken to reduce the accidental release risk. Such measures include recommendations on: plant design practices; prevention, protection, and mitigation technologies; and operation and maintenance practices. Conceptual costs of possible prevention, protection, and mitigation measures are estimated.

17. KEY WORDS AND DOCUMENT ANALYSIS

| a. DESCRIPTORS | b. IDENTIFIERS/OPEN ENDED TERMS | c. COSATI Field/Group |
|---|---|---|
| Pollution | Pollution Control | 13B |
| Chlorohydrocarbons | Stationary Sources | 07C |
| Emission Design | Chloropicrin | 14G |
| Accidents Maintenance | Accidental Releases | 13L |
| Toxicity | | 06T |
| Storage | | 15E |

| 18. DISTRIBUTION STATEMENT | 19. SECURITY CLASS (This Report) | 21. NO. OF PAGES |
|---|---|---|
| Release to Public | Unclassified | 84 |
| | 20. SECURITY CLASS (This page) Unclassified | 22. PRICE |

EPA Form 2220-1 (9-73)

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## ABSTRACT

A strategy for reducing the risk of a major accidental air release of toxic chemicals has developed a strategy for reducing the risk of a major accidental air release of toxic chemicals. The strategy includes monitoring the storage, handling, and use of certain chemicals and providing guidance to industry and communities. This manual summarizes technical information that will assist in identifying and controlling release hazards associated with chloropicrin specific to the SCAQMD.

Chloropicrin gas has an IDLH (Immediately Dangerous to Life and Health) concentration of 1 ppm, which makes it a substantial acute toxic hazard. To reduce the risks associated with an accidental release of chloropicrin, some of the potential causes of accidental releases that apply to processes that use chloropicrin in the SCAQMD must be identified. Examples of potential causes are identified, as are specific measures that may be taken to reduce the accidental release risk. Such measures include recommendations on plant design practices, prevention, protection and mitigation technologies, and operation and maintenance practices. Conceptual cost estimates of possible prevention, protection, and mitigation measures are provided.

ACKNOWLEDGEMENTS

This manual was prepared under the overall guidance and direction of T. Kelly Janes, Project Officer, with the active participation of Robert P. Hangebrauck, William J. Rhodes, and Jane M. Crum, all of U.S. EPA. In addition, other EPA personnel served as reviewers. Sponsorship and technical support was also provided by Robert Antonopolis of the South Coast Air quality Management District of Southern California, and Michael Stenberg of the U.S. EPA, Region 9. Radian Corporation principal contributors involved in preparing the manual were Graham E. Harris (Program Manager), Glenn B. DeWolf (Project Director), Daniel S. Davis, Nancy S. Gates, Jeffrey D. Quass, Miriam Stohs, and Sharon L. Wevill. Contributions were also provided by other staff members. Secretarial support was provided by Robert J. Brouwer and others. Special thanks are given to the many other people, both in government and industry, who served on the Technical Advisory Group and as peer reviewers.

TABLE OF CONTENTS


| Section | | Page |
|---|---|---|
| | ABSTRACT | iii |
| | ACKNOWLEDGEMENTS | iv |
| | FIGURES | vi |
| | TABLES | vii |
| **Section** | | **Page** |
| 1 | INTRODUCTION | 1 |
| | 1.1 Background | 1 |
| | 1.2 Purpose of This Manual | 1 |
| | 1.3 Use of Chloropicrin | 2 |
| | 1.4 Organization of the Manual | 2 |
| 2 | CHEMICAL CHARACTERISTICS | 4 |
| | 2.1 Physical Properties | 4 |
| | 2.2 Chemical Properties and Reactivity | 6 |
| | 2.3 Toxicological and Health Effects | 6 |
| 3 | FACILITY DESCRIPTIONS AND PROCESS HAZARDS | 9 |
| | 3.1 Processing | 9 |
| | 3.2 Storage and Transfer | 11 |
| | 3.3 Potential Causes of Releases | 11 |
| | 3.3.1 Process Causes | 11 |
| | 3.3.2 Equipment Causes | 12 |
| | 3.3.3 Operational Causes | 12 |
| 4 | HAZARD PREVENTION AND CONTROL | 14 |
| | 4.1 General Considerations | 14 |
| | 4.2 Process Design | 15 |
| | 4.3 Physical Plant Design | 15 |
| | 4.3.1 Equipment | 17 |
| | 4.3.2 Plant Siting and Layout | 21 |
| | 4.3.3 Transfer and Transport Facilities | 22 |
| | 4.4 Protection Technologies | 23 |
| | 4.4.1 Enclosures | 23 |
| | 4.4.2 Scrubbers | 24 |
| | 4.5 Mitigation Technologies | 26 |
| | 4.5.1 Secondary Containment System | 26 |
| | 4.5.2 Flotation Devices and Foams | 30 |
| | 4.5.3 Mitigation Techniques for Chloropicrin Vapor | 31 |
| | 4.6 Operation and Maintenance Practices | 33 |
| | 4.7 Control Effectiveness | 34 |

TABLE OF CONTENTS (Continued)


| Section | | Page |
|---|---|---|
| 4.8 | Illustrative Cost Estimates for Controls | 34 |
| 4.8.1 | Prevention and Protection Measures | 36 |
| 4.8.2 | Levels of Control | 36 |
| 4.8.3 | Cost Summaries | 38 |
| 4.8.4 | Equipment Specifications and Detailed Costs | 44 |
| 4.8.5 | Methodology | 44 |
| 5 | REFERENCES | 69 |
| APPENDIX A | GLOSSARY | 71 |
| APPENDIX B | METRIC (SI) CONVERSION FACTORS | 75 |


FIGURES


| Number | | Page |
|---|---|---|
| 3-1 | Conceptual process diagram of a typical batch chloropicrin manufacturing process | 10 |

TABLES


| Number | | Page |
|---|---|---|
| 2-1 | Physical Properties of Chloropicrin | 5 |
| 2-2 | Exposure Limits for Chloropicrin | 7 |
| 2-3 | Predicted Human Health Effects of Exposure to Various Concentrations of Chloropicrin | 8 |
| 4-1 | Key Process Design Considerations and Processes Involving Chloropicrin | 16 |
| 4-2 | Examples of Major Prevention and Protection Measures for Chloropicrin Releases | 35 |
| 4-3 | Estimated Typical Costs of Some Prevention and Protection Measures for Chloropicrin Releases | 37 |
| 4-4 | Summary Cost Estimates of Potential Levels of Controls for Chloropicrin Storage Tank and Batch Reactor | 39 |
| 4-5 | Example of Levels of Controls for Chloropicrin Storage Tank | 40 |
| 4-6 | Example of Levels of Controls for Chloropicrin Manufacture | 42 |
| 4-7 | Estimated Typical Capital and Annual Costs Associated with Baseline Chloropicrin Storage System | 45 |
| 4-8 | Estimated Typical Capital and Annual Costs Associated with Level 1 Chloropicrin Storage System | 46 |
| 4-9 | Estimated Typical Capital and Annual Costs Associated with Level 2 Chloropicrin Storage System | 47 |
| 4-10 | Estimated Typical Capital and Annual Costs Associated with Baseline Continuous Chloropicrin Production | 48 |
| 4-11 | Estimated Typical Capital and Annual Costs Associated with Level 1 Continuous Chloropicrin Production | 49 |
| 4-12 | Estimated Typical Capital and Annual Costs Associated with Level 2 Continuous Chloropicrin Manufacture | 50 |
| 4-13 | Equipment Specifications Associated with Chloropicrin Storage System | 51 |

TABLES (Continued)


| Number | | Page |
|---|---|---|
| 4-14 | Material and Labor Costs Associated with Baseline Chloropicrin Storage System | 53 |
| 4-15 | Material and Labor Costs Associated with Level 1 Chloropicrin Storage System | 54 |
| 4-16 | Material and Labor Costs Associated with Level 2 Chloropicrin Storage System | 55 |
| 4-17 | Equipment Specifications Associated with Chloropicrin Manufacture | 56 |
| 4-18 | Material and Labor Costs Associated with Baseline Continuous Chloropicrin Production | 58 |
| 4-19 | Material and Labor Costs Associated with Level 1 Continuous Chloropicrin Production | 59 |
| 4-20 | Material and Labor Costs Associated with Level 2 Continuous Chloropicrin Production | 60 |
| 4-21 | Format for Total Fixed Capital Cost | 61 |
| 4-22 | Format for Total Annual Cost | 63 |
| 4-23 | Format for Installation Costs | 68 |

# SECTION 1
# INTRODUCTION

## 1.1 BACKGROUND

Recognizing the potential risk associated with accidental releases of air toxics in southern California, the South Coast Air quality Management District (SCAQMD), conducted a study in 1985 to determine the presence, quantities, and uses of hazardous chemicals in the SCAQMD, which includes Los Angeles, Orange, San Bernadino, and Riverside Counties. The SCAQMD study resulted in a report, "South Coast Air Basin Accidental Toxic Air Emissions Study," that outlined an overall strategy for reducing the potential for a major toxic chemical release.

The strategy includes monitoring industry activities associated with storing, handling, and using certain chemicals; using the best technical information available; and guiding industry and communities in reducing the potential for accidental releases and the consequences of any releases that might occur.

Historically, it appears there have been no significant releases of chloropicrin in the SCAQMD. Major incidents elsewhere involving chloropicrin have not been common.

## 1.2 PURPOSE OF THIS MANUAL

This manual compiles technical information on chloropicrin, specifically on preventing accidental releases of chloropicrin. The manual addresses technological and procedural issues associated with storing, handling, and processing chloropicrin as it is used in the SCAQMD.

This manual is not a specification manual, and in fact refers the reader to technical manuals and other sources for more complete information on the topics discussed. Other sources include manufacturers and distributors of chloropicrin, and technical literature on design, operation, and loss prevention in facilities handling toxic chemicals.

## 1.3 USE OF CHLOROPICRIN

Chloropicrin ($CCl_3NO_2$) is manufactured commercially from bleaching powder and picric acid or by the chlorination of nitromethane in the presence of caustic. It is used primarily as an insecticide, as a soil fumigant, and as a warning agent in commercial fumigants. It is also used as a chemical intermediate in the organic synthesis of dyes, as a chemical sterilant, and as a nauseant in chemical warfare. Numerous references in the technical literature describe the manufacture and uses of chloropicrin. Limited survey data indicate that in the SCAQMD, chloropicrin is manufactured from nitromethane and sodium hypochlorite at one site (1). Approximately 10-150 tons of chloropicrin are maintained at this site at any time (1). The chloropicrin is used in the formulation of chloropicrin-methyl bromide mixtures and is shipped to contract fumigators or re-formulators for further use (1).

Storage of chloropicrin appears to be limited to small cylinders (e.g., 150 lb.) and bulk storage tanks.

## 1.4 ORGANIZATION OF THE MANUAL

Following the introductory section, the remainder of the manual presents technical information on specific hazards and categories of hazards and their control as they relate to chloropicrin.

Section 2 discusses physical and chemical properties. Section 3 describes the types of facilities where chloropicrin is used in the SCAQMD and process hazards found in those facilities. Hazard prevention and control are discussed in Section 4, as are costs of example storage and process

facilities, reflecting different levels of control through alternative systems. The examples are for illustration only and do not necessarily represent a satisfactory alternative control option in all cases. Section 5 contains references. Appendix A is a glossary of key technical terms that might not be familiar to all users of the manual, and Appendix B presents selected conversion factors between metric (SI) and English measurement units.

# SECTION 2
# CHEMICAL CHARACTERISTICS

This section of the manual describes the physical, chemical and toxicological properties of chloropicrin as they relate to accidental release hazards.

## 2.1 PHYSICAL PROPERTIES

At room temperature and pressure, chloropicrin is a colorless, oily liquid with a sharp penetrating odor. Some of its common physical properties are shown in Table 2-1.

Chloropicrin is only slightly soluble in water. It is, however, partially soluble in ether, and miscible in benzene, carbon disulfide, and amyl alcohol. In addition, chloropicrin is more dense than water and large spills in water may settle before being totally dispersed or volatilized.

Because it has a relatively high evaporation rate, spills and leaks of chloropicrin can result in hazardous air releases. In addition, since the density of chloropicrin vapor is greater than that of air, it will remain close to the ground, potentially creating a dangerous situation for workers and surrounding communities.

Chloropicrin has a moderately large coefficient of expansion, expanding approximately 5 percent when warmed from 68°F to 140°F (2). Consequently, liquid-full equipment presents a special hazard. A liquid-full vessel is a vessel that is not vented and has little or no vapor space above the liquid. A liquid-full line is a section of pipe sealed off at both ends and full of liquid, with little or no vapor space. In such cases, there is no room for thermal expansion of the liquid and temperature increases can result in containment failure.

TABLE 2-1. PHYSICAL PROPERTIES OF CHLOROPICRIN

| | | Reference |
|---|---|---|
| CAS Registry Number | 76-06-2 | |
| Chemical Formula | $CCl_3NO_2$ | |
| Molecular Weight | 164.4 | |
| Normal Boiling Point | 233.6 °F @ 1 atm | 2 |
| Melting Point | -83.2 °F | 2 |
| Liquid Specific Gravity ($H_2O$=1) | 1.651 @ 68 °F | 3 |
| Vapor Specific Gravity (air=1) | 5.7 @ 233.6°F | 3 |
| Vapor Pressure | 0.35 psia @ 68°F | 2 |
| Vapor Pressure Equation:* | $\log Pv = A - \frac{B}{T+C}$ | 4 |
| | where: Pv = vapor pressure, mmHg | |
| | T = temperature, °C | |
| | A = 7.7911, a constant | |
| | B = 1,823.90, a constant | |
| | C = 259.44, a constant | |
| Solubility in Water | 0.12 $lb/ft^3$ | 3 |
| Specific Heat at Constant Pressure | 0.225 Btu/(lb-°F) | 2 |
| Latent Heat of Vaporization | 99.9 Btu/lb | 2 |
| Liquid Surface Tension | 32.3 dyn/cm @ 68°F | 2 |
| Average Coefficient of Thermal Expansion, 32 °F - 158 °F | 0.00116/°F | 2 |

*Constants were calculated using formula derived in Reference 4 and vapor pressure data from Reference 2.

## 2.2 CHEMICAL PROPERTIES AND REACTIVITY

The most significant properties contributing to a potential accidental release of chloropicrin are:

- Chloropicrin decomposes violently when heated above its normal boiling point of 233.6°F, to severely toxic gases, including nitric oxide, phosgene, nitrosyl chloride, chlorine, and carbon monoxide. The rate of decomposition is increased by contact with metals (2,5).

- Most metals are corroded or tarnished to some degree by chloropicrin. In particular, since chloropicrin severely corrodes aluminum, magnesium and their alloys under certain conditions, they should not be used in chloropicrin service (2).

- Chloropicrin is incompatible with strong oxidizers and contact can result in the formation of flammable and explosive gaseous mixtures (6).

During the process and storage of chloropicrin such conditions should be avoided.

## 2.3 TOXICOLOGICAL AND HEALTH EFFECTS

The toxicological effects of chloropicrin have been well-documented (7). Chloropicrin is a severe irritant to the eyes, skin, and respiratory tract. Exposure results in lachrymation, coughing, nausea, vomiting, bronchitis, and pulmonary edema (6,8,9). An additional toxic effect is that it interferes with oxygen transport by reacting with SH-groups in hemoglobin (8). Vomiting occurs after swallowing saliva in which small amounts of chloropicrin have dissolved. Table 2-2 summarizes some of the relevant exposure limits for

chloropicrin. Table 2-3 summarizes the predicted human health effects of exposure to various concentrations of chloropicrin.

TABLE 2-2. EXPOSURE LIMITS FOR CHLOROPICRIN

| Exposure Limit | Concentration (ppm) | Description | Reference |
|---|---|---|---|
| IDLH | 4 | The concentration defined as posing an immediate danger to life and health (i.e., causes irreversible toxic effects for a 30-minute exposure) | 10 |
| PEL | 0.1 | A time-weighted 8-hour exposure to this concentration, as set by the Occupational Safety and Health Administration (OSHA), should result in no adverse effects for the average worker. | 10 |
| TCLo | 0.3 | This concentration is the lowest published concentration causing toxic effects (irritation) for a 1-minute exposure. | 7 |
| LCLo | 119 | This concentration is the lowest published lethal concentration for a human over a 30-minute exposure. | 7 |

TABLE 2-3. PREDICTED HUMAN HEALTH EFFECTS OF EXPOSURE TO VARIOUS CONCENTRATIONS OF CHLOROPICRIN

| ppm | Predicted Effect |
|---|---|
| 0.3 - 0.37 | Painful eye irritation results in 3 to 30 seconds |
| 1.1 | Odor threshold |
| 4 | Temporarily disabling as a result of irritant effects after a few seconds |
| 15 | Intolerable longer than 1 minute |
| 20 | Causes bronchial or pulmonary lesions after 1 to 2 minutes |
| 119 | Death resulting from pulmonary edema after 30 minutes |

# SECTION 3
# FACILITY DESCRIPTIONS AND PROCESS HAZARDS

This section briefly describes the uses of chloropicrin in the SCAQMD and highlights major process hazards related to accidental releases. Preventive measures associated with these hazards are discussed in Section 4.

## 3.1 PROCESSING

According to the survey data, chloropicrin is manufactured in the SCAQMD by the chlorination of nitromethane and is used to make chloropicrin-methyl bromide mixtures. This section summarizes the major technical features of typical processing and storage facilities that might be found in the SCAQMD and discusses the associated accidental release hazards.

Chloropicrin is manufactured by batch chlorination of nitromethane. Figure 3-1 presents a typical chlorination system.

The process consists of adding over a given period of time a slight excess of nitromethane to an aqueous solution of sodium hypochlorite in a stirred, uncooled batch reactor (9,11). To prevent boiling of the reaction mixture the temperature of the reactor contents is maintained below 165°F by controlling the temperature and concentration of the sodium hypochlorite used.

The primary hazard associated with the manufacture of chloropicrin is the exothermic nature of the chlorination reaction. The potential exists for a runaway reaction, resulting in overheating and overpressure. Adequate temperature control and agitation are required to prevent a hazardous release of toxic material.

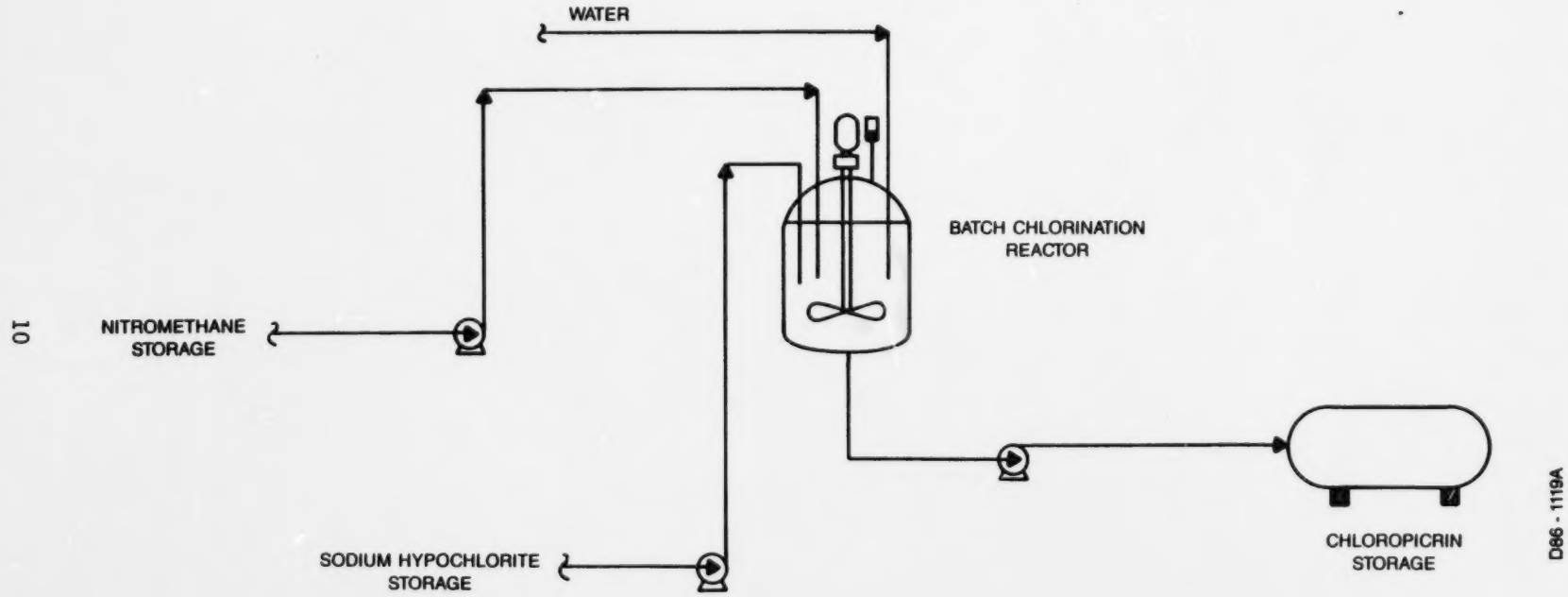


Figure 3-1. Conceptual process diagram of a typical batch chloropicrin manufacturing process.

## 3.2 STORAGE AND TRANSFER

Chloropicrin is stored in low-pressure storage vessels to prevent vapor loss (12,13). Because of the acute toxicity of chloropicrin vapor, a sealed vessel is typically used to prevent breathing loss emissions.

Transfer of chloropicrin involves a closed system (12). Vapor exchange to a tank truck is commonly used when filling a chloropicrin storage tank. The system consists of a pipeline between the vapor spaces of the tank truck and the storage vessel. The vapors can then be displaced from the receiving tank and transported back to the loading terminal. When emptying a chloropicrin storage tank, nitrogen replaces the chloropicrin vapors in the vapor space.

## 3.3 POTENTIAL CAUSES OF RELEASES

Chloropicrin releases can originate from many sources, including leaks or ruptures in vessels, piping, valves, instrumentation connections, and process machinery such as pumps.

Failures leading to accidental releases may be broadly classified as due to process, equipment, or operational problems. The causes of releases discussed below are illustrative and do not exhaust all possibilities.

### 3.3.1 Process Causes

Process causes are related to the fundamentals of process chemistry, control, and general operation. Possible process causes of a chloropicrin release include:

- Excess nitromethane feed to a batch reactor leading to excessive exothermic reaction;

- Excess feeds in any part of the system leading to overfilling or overpressuring equipment;

- Overpressure in chloropicrin storage vessels. This situation may be caused by heat generated by a reaction of chloropicrin with contaminants, fire exposure, or unrelieved overfilling.

### 3.3.2 Equipment Causes

Equipment causes of accidental releases result from hardware failures. Possible causes include:

- Excessive stress due to improper fabrication, constructions, or installation;

- Failure of a vessel due to weakening of equipment from excessive stress, external loadings or corrosion; and

- Pipe or pump failure due to excessive stress, external loading, erosion or corrosion.

### 3.3.3 Operational Causes

Operational causes of accidental releases are a result of incorrect operating and maintenance procedures or human operating errors. These causes include:

- Overfilled storage vessels;

- Improper process system operation;

- Errors in chloropicrin transfer procedures;

- Inadequate maintenance in general, but especially of pressure relief systems and other preventive and protective systems; and

- Lack of inspection and non-destructive testing of vessels and piping to detect corrosion weakening.

# SECTION 4
# HAZARD PREVENTION AND CONTROL

## 4.1 GENERAL CONSIDERATIONS

The prevention of accidental releases relies on a combination of technological, administrative, and operational practices that apply to the design, construction, and operation of facilities where chloropicrin is manufactured, stored and used. Considerations in these areas can be grouped as follows:

- Process design;
- Physical plant design;
- Operating and maintenance practices; and
- Protective systems.

In each of these areas, specific factors must be considered that could lead to a process upset or failure that could directly cause a release of chloropicrin to the environment or result in an equipment failure that would then cause the release. At a minimum, equipment and procedures should be examined to ensure they are in accordance with applicable codes, standards, and regulations. In addition, stricter equipment and procedural specifications should be used if extra protection against a release is considered appropriate.

The following subsections discuss specific considerations regarding release prevention; more detailed discussions will be found in the manual on control technologies.

## 4.2 PROCESS DESIGN

Process design involves the fundamental characteristics of the process by which chloropicrin is manufactured. Any discussions of how process design may be involved in accidental chemical releases must include an evaluation of how deviations from expected process design conditions could initiate a series of events resulting in an accidental release. The primary focus is on how the process is controlled in terms of the basic process chemistry involved, and on the variables of flow, pressure, temperature, composition, and level. Quantity measuring systems, mixing systems, fire protection, and process control instrumentation may also be considered. Modifications to enhance process integrity would involve changes in quantities of materials, in process pressure and temperature conditions, in unit operations and sequence of operations, in process control strategies, and in the instrumentation used.

Table 4-1 shows the relationship between key process design considerations and the individual processes described in Section 3 of this manual. This does not mean that other factors should be ignored, nor that proper attention to the key consideration ensures a safe system. These considerations must be properly addressed, however, to ensure a safe system.

The primary consideration in the manufacture of chloropicrin is preventing overheating and boiling of the batch reactor contents that might lead to overpressure. Equipment failure without overpressure is also possible if corrosion has weakened process equipment.

## 4.3 PHYSICAL PLANT DESIGN

Physical plant design involves equipment, siting and layout, and transfer/transport facilities. Vessels, piping and valve, process machinery, instrumentation, and factors such as location of systems and equipment must all be considered. The following subsections cover various aspects of physical plant design, beginning with a discussion of materials of construction.

TABLE 4-1. KEY PROCESS DESIGN CONSIDERATIONS AND PROCESSES INVOLVING CHLOROPICRIN

| Process Design Consideration | Process or Unit Operation |
|---|---|
| Flow control of feed streams | Batch chloropicrin reactor |
| Temperature monitoring | Batch chloropicrin reactor |
| Adequate pressure relief | Storage tanks and batch chloropicrin reactor |
| Mixing | Batch chloropicrin reactor |
| Corrosion monitoring | Storage tanks and batch chloropicrin reactor |
| Level sensing and control | Storage tanks and batch chloropicrin reactor |

### 4.3.1 Equipment

Materials of Construction--

Practically all metals are corroded or tarnished by chloropicrin, but not enough to prevent their use as construction materials (2). In addition, metals tend to catalyze the decomposition of chloropicrin (2).

Chloropicrin can be stored in a mild steel shell at 140°F for 15 weeks with only a minimum amount of decomposition (2). Although chloropicrin attacks the shell, the degree of corrosion is minimal. It can likewise be stored at room temperature for at least one year with no pronounced changes other than slight corrosion of the shell (2).

Other materials more resistant to the corrosiveness of chloropicrin are the stainless steels, titanium, and nickel-copper and nickel-chromium-molybdenum alloys. However, stainless steel tends to concentration cell corrode (14). This type of corrosion results from a difference in the amount of oxygen in solution at one point as compared with another (15). Corrosion is accelerated where the oxygen concentration is least. This occurs in a stuffing box or under gaskets, for example.

Equipment used in chloropicrin service is commonly lined with tetrafluoropolyethylene, vinylidene chloride, or polyvinylidene fluoride to prevent corrosion (14). Polypropylene resins and polyvinyl chloride are not recommended (14).

Aluminum, magnesium and their alloys should not be used in chloropicrin service since chloropicrin can react violently with these materials (5).

Vessels--

Low pressure storage tanks and batch reactors are used in chloropicrin service (13). Each type of vessel has certain design and fabrication specifications under various codes and standards that should be adhered to.

Chloropicrin shipping containers must meet Department of Transportation (DOT) specifications.

Although exact specifications for batch reactors used in the manufacture of chloropicrin are unavailable, they should at least conform to applicable codes for low-pressure vessels.

Specific release prevention considerations for vessels include overpressure protection, temperature control, and corrosion prevention. Process vessels are usually protected by pressure relief valves and/or rupture discs. The pressure relief valve is set to relieve slightly above the design working pressure of the vessel, but well below the maximum allowable working pressure.

Pressure relief valves and rupture discs are designed to prevent explosion by allowing a controlled release of overpressurized contents. These relief systems are usually sized for flashing liquid caused by (16):

- Fire exposure;
- Thermal expansion;
- Internal reaction/decomposition; and
- Excess supply rates.

Relief piping must be sized for adequate flow. Preventing a relief discharge to the environment requires that the discharge be handled through one of the protection systems discussed in Section 4.4 of this manual.

Piping--

As with chloropicrin vessels, chloropicrin pipework design must reflect the pressure, temperature, and corrosion associated with use of the chemical. Careful attention must be paid to pipework and associated fittings since failures of this type of equipment are major contributors to accidental

releases of chemicals (16). As for all toxic chemicals, there are general guidelines for chloropicrin piping systems (16). The first is simplicity of design; the number of joints and connections should be minimized. In addition to being securely supported, pipes should be sloped, with drainage at the low points. Piping should be constructed to allow room for thermal expansion of the pipe and should be protected from exposure to fire and high temperatures. Placement of valves should ensure isolation of leaking pipes and equipment.

The correct design and use of pipe supports is essential to reducing overstress and vibration that could lead to piping failure. The supports should be designed to handle the load associated with the pipe, operating and testing medium, insulation, and other equipment. Thermal expansion and contraction, vibrations caused by pumping and fluid flow, bending movements resulting from overpressure in the pipe, and external loads such as winds or ice accumulation must all be considered.

All piping should be situated away from fire and fire hazards since chloropicrin can explode violently above its boiling point (2). If possible, piping carrying chloropicrin should not be routed near other processes or piping networks that might present an external threat (e.g., piping carrying highly corrosive materials, high pressure processes). Pipe flanges should be situated to minimize potential hazards from drips and small leaks. In addition, the piping network should be protected from possible impact and other structural damage.

Valves in chloropicrin service include gate, globe, ball, relief, and check configurations; they must be constructed of materials suitable for chloropicrin service.

Check valves, which are a primary means of preventing undesired back or reverse flows, can prevent undesired materials from entering chloropicrin-containing equipment and possible explosive reactions resulting from backups into tanks. Check valves are also used widely on the pump discharges to prevent backflow that could render a pump inoperable and eventually result in a hazardous release.

Process Machinery--

Process machinery is rotating or reciprocating equipment that may be used for transferring or processing chloropicrin.

Pumps--Centrifugal, rotary, positive displacement, and sealless pumps are used to pump chloropicrin. To ensure that a given pump is suitable for chloropicrin service, the system designer should obtain information from the pump manufacturer certifying that the pump will perform properly in this application.

Pumps should be constructed of materials resistant to chloropicrin at operating temperatures and pressures. They should be installed dry and oil-free. The pump's supply tank should have high and low level alarms; the pump should be interlocked to shut off at low supply level or low discharge pressure. External pumps should be situated inside a diked area, and they should be accessible in the event of a tank leak.

In some situations, the potential for seal leakage rules out the use of rotating shaft seals. Pump types that either isolate the seals from the process stream, or eliminate them altogether include canned-motor pumps, vertical extended-spindle submersible pumps, magnetically coupled pumps and diaphragm pumps (15,16).

Canned motor pumps are centrifugal units in which the motor housing is interconnected with the pump casing. Here, the process liquid actually serves as the bearing lubricant. An alternative concept is the vertical pump often used on storage tanks. These pumps consist of a submerged impeller housing connected by an extended drive shaft to the motor. The advantages are that the shaft seal is above the maximum liquid level (and is therefore not wetted by the pumped liquid) and the pump is self priming because the liquid level is above the impeller.

Magnetically-coupled pumps replace the drive shaft with a rotating magnetic field as the pump-motor coupling device.

Diaphragm pumps are positive displacement units in which a reciprocating flexible diaphragm drives the fluid. This arrangement eliminates exposure of packing and seals to the pumped liquid; however, at some point, the diaphragm will probably fail and such a failure could lead to a release. These pumps usually have a pressure relief valve on the outlet, bypassing to the suction.

Improper operation of pumps, i.e., running dry and deadheading, can damage and cause failure of pumps. Running a pump dry because of loss of head in a feed tank, for example, can seriously damage a pump. Pumping against a closed valve can also have serious ramifications, causing a temperature rise of the liquid within the pump. This heating could result in thermal decomposition of the chloropicrin within the pump, which could lead to an accidental release. Such an occurrence may be avoided with a pump bypass or kick-back loop. Failure of a pump, for whatever reason, can eventually lead to a hazardous release.

### 4.3.2 Plant Siting and Layout

The siting and layout of a chloropicrin facility requires careful consideration of numerous factors, including: other processes in the area, the proximity of population centers, prevailing winds, local terrain, and potential natural external effects such as flooding.

The siting of facilities or individual equipment items should reduce personnel exposure, both plant and public, in the event of a release. Since other siting considerations are also important, there may be trade-offs between this requirement and other safety-related requirements in a process. Siting should allow ready ingress or egress in the event of an emergency and yet also take advantage of barriers, either man-made or natural, that could reduce the consequences of a release.

Various techniques available for formally assessing a plant layout should be considered when planning high hazard facilities (16).

General layout considerations include:

- Large inventories of chloropicrin should be kept away from sources of fire or explosion hazard;
- Vehicular traffic should not go too near chloropicrin manufacture or storage areas if it can be avoided;
- Where such traffic is necessary, precautions should be taken to reduce the chances of vehicular collisions with equipment, especially pipe racks carrying chloropicrin across or next to roadways; and
- Storage facilities should be segregated from the main process unless the hazards of pipe transport are felt to outweigh the hazard of the storage tank for site-specific cases.

In the event of an emergency, there should be multiple means of access to the facility for emergency vehicles and crews. Storage vessel shut-off valves should be readily accessible. Containment for liquid storage tanks can be provided by diking. Dikes reduce evaporation while containing the liquid. It is also possible to design the drainage of a diked area to an underground containment sump.

### 4.3.3 Transfer and Transport Facilities

Transfer and transport facilities where both road and rail tankers are loaded or unloaded are likely accident areas because of vehicle movement and

the intermittent nature of the operations. Special attention should be given to the design of these facilities.

Tank car and tank truck facilities should be located away from sources of heat, fire, and explosion. Equipment in these areas should also be protected from impact by vehicles and other moving equipment. Tank vehicles should be securely moored during transfer operations; an interlocked barrier system is commonly used. Sufficient space should be available to avoid congestion of vehicles or personnel during loading and unloading operations. Vehicles, especially trucks, should be able to move into and out of the area without reversing. High curbs around transfer areas and barriers around equipment should be provided to protect equipment from vehicle collisions.

## 4.4 PROTECTION TECHNOLOGIES

This section describes two types of protection technologies for containment and neutralization:

- Enclosures, and
- Scrubbers.

### 4.4.1 Enclosures

Enclosures refer to containment structures that capture any chloropicrin spilled or vented from storage or process equipment, thereby preventing immediate discharge of the chemical to the environment. The enclosures contain the spilled liquid or vapor until it can be transferred to other containment, discharged at a controlled rate that would not be injurious to people or to the environment, or transferred at a controlled rate to scrubbers for neutralization.

The location of toxic operations in the open air has been favorably mentioned in the literature (16), but so has the opposing idea that sometimes

enclosure may be appropriate. The practicability of using an enclosure depends partly on how often personnel must be involved with the equipment. A common design rationale for not having an enclosure where toxic materials are used is to prevent the accumulation of toxic concentrations within enclosed areas. However, if the issue is protecting the community from accidental releases, then total enclosure may be appropriate. Enclosures should be equipped with continuous monitoring equipment and alarms. Alarms should sound whenever lethal or flammable concentrations are detected.

Care must be taken when a enclosure is built around pressurized equipment. It would not be practical to design an enclosure to withstand the pressures associated with the sudden release of a pressurized vessel. An enclosure would probably fail from the pressure created from such a release, creating an additional hazard. In these situations, an enclosure may not be appropriate. If an enclosure is built around pressurized equipment, it should be equipped with some type of explosion protection, such as rupture plates designed to fail before the entire structure fails.

The type of structures that appear to be suitable for chloropicrin are concrete blocks, or concrete sheet buildings or bunkers. An enclosure would have a ventilation system designed to draw in air when the building is vented to a scrubber. The bottom section of the building used for stationary storage containers should be liquid tight to retain any chloropicrin that might be spilled.

### 4.4.2 Scrubbers

Scrubbers, which are a traditional method for absorbing toxic gases from process streams, can be used for controlling chloropicrin releases from vents and pressure relief discharges, from process equipment, or from secondary containment enclosures.

Chloropicrin discharges could be contacted with an aqueous scrubbing medium in any of several types of scrubbing devices. An alkaline solution is needed to achieve effective absorption because absorption rates with water alone would require unreasonably high liquid-to-gas ratios. A typical alkaline solution for an emergency scrubber is calcium hydroxide derived from slaked lime.

Types of scrubbers that might be appropriate include spray towers, packed bed scrubbers, and venturis. Other special designs might be suitable, but complex internals subject to corrosion do not seem appropriate.

Whatever type of scrubber is selected, a complete system would include the scrubber itself, a liquid feed system, and reagent makeup equipment. If such a system is used as protection against emergency releases, one must consider how it would be activated in time to respond to an emergency load. In some process facilities, a continuous circulation of scrubbing liquor is maintained through the system. For many facilities this would not be practical, and the scrubber system might be tied into a trip system that turns it on when needed.

Venturi scrubbers have an advantage when the scrubbing system is activated by a trip system. A venturi scrubber can create its own draw of vapor by the flow of the scrubbing medium, so that the trip system need only turn on the flow of liquid to the scrubber, rather than turn on the flow of liquid and start up a blower, as would be required by alternate types of scrubbing systems.

Another approach is the drowning tower where the chloropicrin vent is routed to the bottom of a large tank of uncirculating caustic. The drowning tower does not have the high contact efficiency of the other types, but can provide substantial capacity on demand as long as the back pressure of the hydrostatic head does not create a secondary hazard, by impeding an overpressure relief discharge, for example.

## 4.5 MITIGATION TECHNOLOGIES

If, in spite of all precautions, a large release of chloropicrin occurs, the first priority is to rescue workers in the immediate vicinity of the accident and evacuate persons from downwind areas. The source of the release should be determined, and the leak should be plugged to stop the flow, if this is possible. The next primary concern is to reduce the effects of the released chemical on the plant and the surrounding community. Reducing the consequences of an accidental release of a hazardous chemical is referred to as mitigation. Mitigation technologies include such measures as physical barriers, water sprays and fogs, and foams, where applicable. The purpose of a mitigation technique is to divert, limit, or disperse a chemical that has been spilled or released to the atmosphere to reduce the atmospheric concentration and the affected area. In addition, secondary containment systems such as impounding basins, dikes, and flotation devices and/or foams are used to reduce the rate of evaporation from a spilled liquid. The mitigation technology chosen for a particular chemical depends on the specific properties of the chemical: its flammability, toxicity, reactivity, and those properties that determine its dispersion characteristics in the atmosphere.

A post-release mitigation effort requires that the source of the release be accessible to trained plant personnel. Therefore, the availability of adequate personnel protection is essential. Personnel protection typically includes such items as portable breathing air and chemically resistant protective clothing.

### 4.5.1 Secondary Containment Systems

Specific types of secondary containment systems include excavated basins, natural basins, earth, steel, or concrete dikes and high impounding walls. The type of containment system best suited for a particular storage tank or process unit will depend on the risk associated with an accidental release from that location. The inventory of chloropicrin and its proximity to other

portions of the plant and to the community should be considered when selecting a secondary containment system. The secondary containment system should have the ability to contain spills with a minimum of damage to the facility and its surroundings and with minimum potential for escalation of the event.

Secondary containment systems for chloropicrin storage facilities commonly consist of one of the following:

- An adequate drainage system underlying the storage vessels that terminates in an impounding basin whose capacity is as large as that of the largest tank served;

- A diked area whose capacity is as large as that of the largest tank served.

These measures are designed to prevent the accidental discharge of chloropicrin from spreading to uncontrolled areas.

The most common type of containment system is a low wall dike surrounding one or more storage tanks. Generally, no more than three tanks are enclosed within one area because of increased risk. Dike heights usually range from three to twelve feet. The dike walls should be liquid tight and able to withstand the hydrostatic pressure and temperature of a spill. Low-wall dikes may be constructed of steel, concrete, or earth. Dike walls must be constructed and maintained to prevent leakage through the dike. Piping should be routed over dike walls, and penetrations through the walls should be avoided if possible. Vapor fences may be situated on top of the dikes to provide adequate vapor storage capacity. If there is more than one tank in the diked area, the tanks should be situated on berms above the maximum liquid level attainable in the impoundment.

A low-wall dike can effectively contain the liquid portion of an accidental release and keep the liquid from entering uncontrolled areas. By

preventing the liquid from spreading, the low-wall dike can also reduce the surface area of the spill; reducing the surface area reduces the rate of evaporation. The low-wall dike will partially protect the spill from wind, which can also reduce the rate of evaporation. A dike with a vapor fence will provide extra protection from wind and will be even more effective at reducing the rate of evaporation.

A remote impounding basin is well-suited to storage systems serving more than one tank where a relatively large site is available. The flow from a chloropicrin spill is directed to the basin by dikes and channels under the storage tanks; the channels are designed to minimize exposure of the liquid to other tanks and surrounding facilities. Because chloropicrin evaporates at a relatively rapid rate, the trenches that lead to the remote impounding basin as well as the basin itself should be covered to reduce the rate of evaporation. Also, the impounding basin should be located near the tank to minimize the amount of chloropicrin that evaporates as it travels to the basin.

This type of system has several advantages. The spilled liquid is removed from the immediate tank area, allowing access to the tank during the spill and reducing the probability that the spilled liquid will damage the tank, piping, electrical equipment, pumps or other equipment.

High- wall impoundments may be the best secondary containment choice for selected systems. Circumstances that may warrant their use include limited storage site area, the need to minimize vapor generation rates, and/or the need for the tank to be protected from external hazards. Maximum vapor generation rates will generally be lower for a high-wall impoundment than for low-wall dikes or remote impoundments because of the reduced surface contact area. These rates can be further reduced by using insulation on the wall and floor in the annular space. High impounding walls may be constructed of low-temperature steel, reinforced concrete, or prestressed concrete. A weather shield may be provided between the tank and wall with the annular space

remaining open to the atmosphere. The available area surrounding the storage tank will dictate the minimum height of the wall. For high-wall impoundments, the walls may be designed with a volumetric capacity greater than that of the tank for containing vapors. Increasing the height of the wall also raises the elevation of any released vapor.

One disadvantage of these dikes is that the high walls around a tank may hinder routine external observation. Furthermore, the closer the wall is to the tank, the more difficult it becomes to reach the tank for inspections and maintenance. As with low wall dikes, piping should be routed over the wall if possible. The closeness of the wall to the tank may require that the pump be placed outside the wall, in which case the outlet (suction) line will have to pass through the wall. In such a situation, a low dike encompassing the pipe penetration and pump may be provided, or a low dike may be placed around the entire wall.

A further type of secondary containment system is structurally integrated with the primary system to form a vapor-tight enclosure around the primary container. Many arrangements are possible. A double-walled tank is an example of such an enclosure. These systems may be considered when protecting the primary container and containing vapor for events not involving foundation or wall penetration failure are of greatest concern. The drawbacks of an integrated system are the greater complexity of the structure, the difficulty of access to certain components, and the fact that complete vapor containment cannot be guaranteed.

The ground within an enclosure should be graded so that the spilled liquid can accumulate at one side or in one corner. This will help minimize the area of ground to which the liquid is exposed and from which it may gain heat. In areas where it is critical to minimize vapor generation, surface insulation may be used in the diked area or impoundment to further reduce heat transfer from the environment to the spilled liquid. The floor of an

impoundment may be sealed with a clay blanket to prevent the chloropicrin from seeping into the ground.

### 4.5.2 Flotation Devices and Foams

A common technique for reducing the hazards associated with a chloropicrin spill is to spread soda ash on the spill, dilute with water, and allow the mixture to stand for several hours (5). The chloropicrin slowly reacts with the soda ash to form products that can be neutralized with a dilute acidic solution and disposed of.

Other possible ways of reducing the surface area of spilled chemicals include placing impermeable flotation devices on the surface and applying foams.

Placing an impermeable flotation device over a spilled chemical is a direct and efficient way of containing toxic vapors. However, being able to use such devices requires acquisition in advance of a spill and storage until needed, and in all but small spills deployment may be difficult. In addition, material and dispersal equipment costs are a major deterrent to their use (17).

The use of foams in vapor hazard control has been demonstrated for a broad range of volatile chemicals. Unfortunately, it is difficult to accurately quantify the benefits of foam systems, because the effects will vary as a function of the chemical spilled, foam type, spill size, and atmospheric conditions. With some materials, foams have a net positive effect, but with others foams may exaggerate the hazard (17).

Little or no information is available concerning the success of foam systems in controlling hazardous chloropicrin releases. However, based on research on chemicals similar in nature to chloropicrin, a net positive effect would be expected (17). The extent of the reduction in concentration for

chloropicrin will depend on the type of foam used. Research in this area has indicated that foams with a medium to high expansion ratio (300 to 350:1) give significantly better results than do foams with low expansion ratios (6 to 8:1) (17). The expansion ratio is the ratio of the volume of foam produced to the volume of solution fed to the foam-generating device.

Regardless of the type of foam used, the slower the foam drainage rate, the better its performance will be. A slow draining foam will spread more evenly, show more resistance to temperature and pH effects, and collapse more slowly. The initial cost of a slow-draining foam may be higher than for other foams, but a cost-effective system will be realized in superior performance.

### 4.5.3 Mitigation Techniques for Chloropicrin Vapor

The extent to which the escaped chloropicrin vapor can be quickly removed or dispersed will be a function of the quantity of vapor released, the ambient conditions, and the physical characteristics of the vapor cloud. The behavior and characteristics of the chloropicrin cloud will depend on a number of factors, including the physical state of the chloropicrin before its release, the location of the release, and the atmospheric and environmental conditions. Many possibilities exist concerning the shape and motion of the vapor cloud, and a number of predictive models of dispersion have been developed. Because of the higher specific gravity of pure chloropicrin, large accidental releases of this chemical will often lead to the formation of chloropicrin-air mixtures that are more dense than the surrounding atmosphere. This type of vapor cloud is especially hazardous, because it will spread laterally and remain close to the ground.

One means of dispersing and removing toxic vapor from the air is with water sprays or fogs. However, to be effective, an impractically large volume of water would have to be used since chloropicrin has a low solubility in water. An alternative is to use a mild aqueous alkaline spray system such as an ammonia-injected water spray system that would neutralize the acid.

The dispersing medium is commonly applied to the vapor cloud with hand-held hoses and/or stationary spray barriers. For effective absorption, it is important to direct fog or spray nozzles from a downwind direction to avoid driving the vapors downwind more quickly. Other important factors relating to the effectiveness of alkaline sprays are the distance of the nozzles from the point of release, the fog pattern, nozzle flow rate, pressure, and nozzle rotation. If the right strategy is followed, a "capture zone" can be created downwind of the release into which the chloropicrin vapor will drift and be absorbed. In low-wind conditions, two fog nozzles should be placed upwind of the release to ensure that the chloropicrin cloud keeps moving downwind against the fog nozzle pressures.

Spray barriers consist of a series of spray nozzles that can be directed either up or down. These barriers can be placed downwind of the source to absorb some of the chloropicrin vapors passing through without major distortion of the chloropicrin cloud (17). Several fog nozzles may be situated farther downwind to absorb additional vapors getting through.

Another way of dispersing a vapor cloud is to use large fans or blowers that direct the vapor away from populated or other sensitive areas (13). However, this method would only be feasible in very calm weather and in sheltered areas; it would not be effective in any wind and would be difficult to control if the release occupied a large open area. A large, mechanical blower would also be required, which decreases the reliability of this mitigation technique.

In general, techniques used to disperse or control vapor emissions should be simple and reliable. In addition to the mitigation techniques discussed above, physical barriers such as buildings and rows of trees can help contain the vapor cloud and control its movement. Hence, reducing the consequences of a hazardous vapor cloud can actually begin with a carefully planned layout of facilities.

## 4.6 OPERATION AND MAINTENANCE PRACTICES

Accidental release of toxic materials result not only from deficiencies of design but also from deficiencies of operation. Thus safe operation of plants using chloropicrin requires competent and experienced managers and staff, in addition to a well considered and fully understood system of work.

Employees should be trained about the important aspects of handling chloropicrin, including: the proper way to handle and store the chemical, hazards resulting from improper use and handling, prevention of spills, cleanup procedures, maintenance procedures and emergency procedures. Well-defined practices and procedures can decrease the possibility of a hazardous release and can also reduce the magnitude of an accidental release.

Proper maintenance and modification programs should be incorporated into plant design and operation to prevent possible hazardous releases of chloropicrin. Maintenance practices for chloropicrin should include special attention to those equipment items previously identified as especially important to chloropicrin manufacture and storage. Preventing equipment failures that could lead to overheating (temperatures above 233.6°F) is crucial to preventing potentially explosive decomposition since this is a special characteristic of chloropicrin. Ensuring the use of proper construction materials in all repairs or replacements of equipment is important. Maintenance practices should also ensure that contact of chloropicrin with strong oxidizers is prevented. Other aspects of a sound maintenance program include special care for corrosion monitoring, relief valve testing, and general maintenance of those areas of the facility with the largest inventories of chloropicrin. All modifications should be formally approved to ensure that modifications do not create a new potential release hazard in the modified system.

## 4.7 CONTROL EFFECTIVENESS

It is difficult to quantify the control effectiveness of preventive and protective measures in reducing the probability and magnitude of accidental releases. Preventive measures, which may involve numerous combinations of process design, equipment design, and operational measures, are especially difficult to quantify because they reduce a probability rather than a physical quantity of a chemical release. Protective measures are more analogous to traditional pollution control technologies. Thus, it may be easier to quantify their efficiency in reducing a quantity of chemical that could be released.

Preventive measures reduce the probability of an accidental release by increasing the reliability of process systems operations and equipment. Control effectiveness can thus be expressed for both qualitative and quantitative improvements by probabilities. Table 4-2 summarizes some of the major design, equipment, and operational measures for the hazards identified for chloropicrin applications in the SCAQMD. The items listed in Table 4-2 are for illustration only and do not necessarily represent a satisfactory control option in all cases. When viewed from a broad perspective, these control options seem to reduce the risk associated with an accidental release, however, there are undoubtedly specific cases where these control options will not be appropriate. Each case must be evaluated individually.

## 4.8 ILLUSTRATIVE COST ESTIMATES FOR CONTROLS

This section presents cost estimates for different levels of controls and for specific release prevention and protection measure that might be found in the SCAQMD for chloropicrin process facilities.

TABLE 4-2. EXAMPLES OF MAJOR PREVENTION AND PROTECTION MEASURES FOR CHLOROPICRIN RELEASES

| Hazard Area | Prevention/Protection |
|---|---|
| Reactor feed streams | Redundant flow control loops; minimal overdesign of feed systems |
| Line, pipe, and valve failure | More frequent inspections and maintenance |
| Human error | Increased training and supervision; use of checklists; use of automatic systems |
| Container failure | Adequate pressure relief; inspection and maintenance; corrosion monitoring; siting away from fire and mechanical damage |
| Vehicular collusions | Location; physical barriers warning signs; training |
| Corrosion | Inspections, maintenance, and corrosion monitoring |
| Overheated reactor | Redundant temperature sensing and alarms; interlocked nitromethane feed shut off |
| Overpressure | Enhanced pressure relief; not isolatable; adequate size; discharge not restricted |
| Overfilling | Redundant level sensing, alarms and interlocks, training of operators |
| Atmosphere releases from relief discharges | Emergency vent scrubber system |
| Storage tank or line rupture | Enclosure vented to emergency scrubber system; diking; foams; neutralization; inspection and non-destructive testing |

### 4.8.1 Prevention and Protection Measures

Preventive measures reduce the probability of an accidental release from a process or storage facility by increasing the reliability of both process systems operations and equipment. Along with an increase in the reliability of a system is an increase in the capital and annual costs associated with incorporating prevention and protection measures into a system. Table 4-3 presents costs of some of the major design, equipment, and operational measures applicable to the primary hazards identified in Table 4-2 for chloropicrin facilities in the SCAQMD.

### 4.8.2 Levels of Control

The prevention of accidental releases relies on a combination of technological, administrative, and operational practices as they apply to the design, construction, and operation of facilities where hazardous chemicals are used and stored. At minimum, equipment and procedures should be in accordance with applicable codes, standards, and regulations; however, additional measures can provide extra insurance against an accidental release.

The levels of control concept is a way of assigning costs to increased levels of prevention and protection. The minimum level is referred to as the "Baseline" system, which consists of the elements required for normal safe operation and basic prevention of an accidental release of hazardous material.

The second level of control is "Level 1," which includes the baseline system with added modifications, such as improved materials of construction, additional controls, and generally more extensive release prevention measures. The costs associated with this level are higher than the baseline system costs.

The third level of control is "Level 2." This system incorporates both the "Baseline" and "Level 1" systems with additional modifications designed

TABLE 4-3. ESTIMATED TYPICAL COSTS OF SOME PREVENTION AND PROTECTION MEASURES FOR CHLOROPICRIN RELEASES[a]

| Prevention/Protection Measure | Capital Cost (1986 $) | Annual Cost (1986 $/yr) |
|---|---|---|
| Pressure relief | | |
| - relief valve | 1000-2000 | 120-250 |
| - rupture disk | 1000-1200 | 120-150 |
| Physical barriers | | |
| - curbing | 750-1000 | 90-120 |
| - 3 ft retaining wall | 1500-2000 | 175-250 |
| Flow control loop | 4000-6000 | 500-750 |
| Temperature sensor | 250-400 | 30-50 |
| Interlock system for feed shut-off | 1500-2000 | 175-250 |
| Alarm system | 250-500 | 30-75 |
| Diking | | |
| - 3 ft high | 1200-1500 | 150-175 |
| - top of tank height | 7000-7500 | 850-900 |
| Corrosion monitoring[b] | | 200-400 |
| Increased inspections and maintenance[c] | | 250-500 |

[a]Based on a 10,000 gallon fixed chloropicrin storage system and a 2,000 gallon batch chlorination reactor system.

[b]Based on 10-20 hr @ $20/hr.

[c]Based on 12.5-25 hr @ $20/hr.

specifically for the prevention of an accidental release, such as alarm and interlock systems. The extra accidental release prevention measures incorporated into "Level 2" are reflected in its cost, which is much higher than that of the baseline system.

When comparing the costs of the various levels of control, it is important to realize that higher costs do not necessarily imply improved safety. The measures applied must be applied correctly. Inappropriate modifications or add-ons may not make a system safer. Each added control option increases the complexity of a system. In some cases the hazards associated with the increased complexity may outweigh the benefits derived from the particular control option. Proper design and construction along with proper operational practices are needed to assure safe operation.

These estimates are for illustrative purposes only. It is doubtful that any specific installation would find all of the control options listed in these tables appropriate for their purposes. An actual system is likely to incorporate some items from each level of control and also some control options not listed here. The purpose of these estimates is to illustrate the relationship between cost and control, not to provide an equipment check list.

Levels of control cost estimates were prepared for a 69-ton fixed chloropicrin storage tank with 10,000 gal capacity and a chloropicrin reactor system. These systems are representative of storage and process facilities that might be found in the SCAQMD.

### 4.8.3 Cost Summaries

Table 4-4 summarizes the total capital and annual costs for each of the three levels of control for a chloropicrin storage system and a chloropicrin reactor system. The costs presented correspond to the systems described in Table 4-5 and Table 4-6. Each of the level costs include the cost of the basic system plus any controls. Specific cost information and breakdown for

TABLE 4-4. SUMMARY COST ESTIMATES OF POTENTIAL LEVELS OF CONTROLS FOR CHLOROPICRIN STORAGE TANK AND BATCH REACTOR

| System | Level of Control | Total Capital Cost (1986 $) | Total Annual Cost (1986 $/yr) |
|---|---|---|---|
| Chloropicrin Storage Tank; 69 ton Fixed Storage Tank With 10,000 gallon Capacity | Baseline | 40,000 | 5,600 |
| | Level No. 1 | 363,000 | 43,000 |
| | Level No. 2 | 532,000 | 63,000 |
| Chloropicrin Reactor System With 2,000 gallon Batch Chlorination Reactor | Baseline | 62,000 | 9,000 |
| | Level No. 1 | 368,000 | 46,000 |
| | Level No. 2 | 445,000 | 53,000 |

TABLE 4-5: EXAMPLE OF LEVELS OF CONTROLS FOR CHLOROPICRIN STORAGE TANK

Process: 69 ton fixed chloropicrin storage tank
10,000 gal

| Controls | Baseline | Level No. 1 | Level No. 2 |
|---|---|---|---|
| Process: | None | None | None |
| Flow: | Single check-valve on tank-process feed line. | Add second check valve. | Add a reduced-pressure device[a] with internal air gap and relief vent to containment tank or scrubber. |
| Temperature: | None | None | Add temperature indicator. |
| Pressure: | Single pressure relief valve, vent to atmosphere. | Add second relief valve, secure non-isolatable. Vent to limited scrubber. Provide local pressure indicator. | Add rupture disks under relief valves. Provide local pressure indication on space between disk and valves. |
| Quantity: | Local level indicator. | Add remote level indicator. | Add level alarm. Add high-low level interlock shut-off for both inlet and outlet lines. |
| Location: | Away from traffic. | Away from traffic and flammables. | Away from traffic, flammables, and other hazardous processes. |
| Materials of Construction: | Carbon steel | Carbon steel with added corrosion allowance. | Kynar®-lined carbon steel. |
| Vessel: | Tank pressure rating: 15 psig | Tank pressure rating: 25 psig | Tank pressure rating: 50 psig |
| Piping: | Sch. 40 carbon steel. | Sch. 80 carbon steel. | Sch 80 Kynar®-lined carbon steel. |

(Continued)

[a]A reduced pressure device is a modified double check valve.

TABLE 4-5 (Continued)

Process: 69 ton fixed chloropicrin storage tank
10,000 gal

| Controls | Baseline | Level No. 1 | Level No. 2 |
|---|---|---|---|
| Process Machinery: | Centrifugal pump, carbon steel, stuffing box seal. | Centrifugal pump, Kynar®-lined construction, double capacity mechanical seal. | Magnetically-coupled centrifugal pump, Kynar®-lined construction. |
| Enclosures: | None | Steel building. | Concrete building. |
| Diking: | None | 3 ft high dike. | Top of tank height, 10 ft. |
| Scrubbers: | None | Alkaline scrubber. | Same |
| Mitigation: | None | Alkaline sprays. | Foam system. |

TABLE 4-6. EXAMPLE OF LEVELS OF CONTROLS FOR CHLOROPICRIN MANUFACTURE

Process: Batch chlorination reactor system

| Controls | Baseline | Level No. 1 | Level No. 2 |
|---|---|---|---|
| Process: | None | Add reactor cooling system. | Use of interlock systems. |
| Temperature: | Local temperature indicator. | Add redundant sensing and alarm. Add remote indicator. | Add temperature switch to shut off nitromethane feed when temperature rises above a set point. |
| Pressure: | Single pressure relief valve. Vent to atmosphere. | Add local pressure indicator on tank. Vent relief valve to scrubber. | Add rupture disk and provide local pressure indication on space between disk and valve. |
| Flow: | Local flow indicator on feed lines. | Add remote indicators. | Add flow switch to shut off nitromethane feed. |
| Quantity: | None | None | Level alarm. |
| Mixing: | Provide adequate mixing. | Add alarm on loss of agitation. | Interlock nitromethane feed on loss of mixing. |
| Composition: | None | None | None |
| Corrosion: | Visual inspections. | Increased monitoring and inspections. | Same |
| Materials of Construction: | Carbon steel | Carbon steel with added corrosion allowance. | Type Kynar®-lined carbon steel. |

(Continued)

TABLE 4-6 (Continued)

Process: Batch chlorination reactor system

| Controls | Baseline | Level No. 1 | Level No. 2 |
|---|---|---|---|
| Vessel: | Tank pressure rating: 25 psig | Tank pressure rating: 25 psig | Tank pressure rating: 25 psig |
| Piping: | Sch. 40 carbon steel. | Sch. 80 carbon steel. | Sch. 80 Kynar®-lined carbon steel. |
| Process Machinery: | Centrifugal pump, carbon steel construction, stuffing box. | Centrifugal pump Kynar®-lined construction, double mechanical seal. | Magnetically-couple centrifugal pump, Kynar®-lined construction. |
| Protective Barrier: | None | Curing around reactor. | 3 ft. high retaining wall. |
| Enclosures: | None | Steel building. | Concrete building. |
| Scrubbers: | None | Alkaline scrubbers. | Same |
| Mitigation: | None | Alkaline sprays. | Foam system. |

each level of control for both the storage and process facilities are presented in Tables 4-7 through 4-12.

### 4.8.4 Equipment Specifications and Detailed Costs

Equipment specifications and details of the capital cost estimates for the chloropicrin storage and the chloropicrin reactor systems are presented in Tables 4-13 through 4-20.

### 4.8.5 Methodology

Format for Presenting Cost Estimates--

Tables are provided for control schemes associated with storage and process facilities for chloropicrin showing capital, operating, and total annual costs. The tables are broken down into subsections comprising vessels, piping and valves, process machinery, instrumentation, and procedures and practice. Presenting the costs in this manner allows for easy comparison of specific items, different levels, and different systems.

Capital Cost--All capital costs presented in this report are shown as total fixed capital costs. Table 4-21 defines the cost elements comprising total fixed capital as it is used here.

The computation of total fixed capital, as shown in Table 4-21, begins with the total direct cost for the system under consideration. This total direct cost is the total direct installed cost of all capital equipment comprising the system. Depending on the specific equipment item involved, the direct capital cost was available or was derived from uninstalled costs by computing costs of installation separately. To obtain the total fixed capital cost, other costs obtained by using factors are added to the total fixed direct costs.

TABLE 4-7. ESTIMATED TYPICAL CAPITAL AND ANNUAL COSTS ASSOCIATED WITH BASELINE CHLOROPICRIN STORAGE SYSTEM

| | Capital Cost (1986 $) | Annual Cost (1986 $/Yr) |
|---|---|---|
| VESSELS: | | |
| Storage Tank | 26,000 | 3,000 |
| PIPING AND VALVES: | | |
| Pipework | 3,000 | 350 |
| Check Valves | 290 | 30 |
| Ball Valves (5) | 1,700 | 200 |
| Relief Valve | 1,000 | 120 |
| PROCESS MACHINERY: | | |
| Centrifugal Pump | 5,400 | 620 |
| INSTRUMENTATION: | | |
| Pressure Gauges (4) | 1,500 | 170 |
| Liquid Level Gauge | 1,500 | 170 |
| PROCEDURES AND PRACTICES: | | |
| Visual Tank Inspection (external) | | 15 |
| Visual Tank Inspection (internal) | | 60 |
| Relief Valve Inspection | | 15 |
| Piping Inspection | | 300 |
| Piping Maintenance | | 120 |
| Valve Inspection | | 30 |
| Valve Maintenance | | 350 |
| TOTAL COSTS | 40,000 | 5,600 |

TABLE 4-8. ESTIMATED TYPICAL CAPITAL AND ANNUAL COSTS ASSOCIATED WITH LEVEL 1 CHLOROPICRIN STORAGE SYSTEM

| | Capital Cost (1986 $) | Annual Cost (1986 $/yr) |
|---|---|---|
| VESSELS: | | |
| Storage Tank | 53,000 | 6,200 |
| PIPING AND VALVES: | | |
| Pipework | 4,000 | 520 |
| Check Valves | 560 | 70 |
| Ball Valves (5) | 1,700 | 200 |
| Relief Valve | 2,000 | 240 |
| PROCESS MACHINERY: | | |
| Centrifugal Pump | 13,000 | 1,500 |
| INSTRUMENTATION: | | |
| Pressure Gauges (4) | 1,500 | 170 |
| Flow Indicator | 3,700 | 430 |
| Liquid Level Gauge | 1,500 | 170 |
| Remote Level Indicator | 1,900 | 220 |
| ENCLOSURES: | | |
| Steel Building | 10,000 | 1,200 |
| SCRUBBER: | | |
| Alkaline Scrubber | 269,000 | 31,000 |
| DIKING: | | |
| 3 ft. High Concrete Diking | 1,300 | 160 |
| PROCEDURES AND PRACTICES: | | |
| Visual Tank Inspection (external) | | 15 |
| Visual Tank Inspection (internal) | | 60 |
| Relief Valve Inspection | | 30 |
| Piping Inspection | | 300 |
| Piping Maintenance | | 120 |
| Valve Inspection | | 35 |
| Valve Maintenance | | 400 |
| TOTAL COSTS | 363,000 | 43,000 |

TABLE 4-9. ESTIMATED TYPICAL CAPITAL AND ANNUAL COSTS ASSOCIATED WITH LEVEL 2 CHLOROPICRIN STORAGE SYSTEM

| | Capital Cost (1986 $) | Annual Cost (1986 $/yr) |
|---|---|---|
| VESSELS: | | |
| Storage Tank | 173,000 | 20,000 |
| PIPING AND VALVES: | | |
| Pipework | 10,000 | 1,100 |
| Reduced Pressure Device | 1,500 | 170 |
| Ball Valves (5) | 1,700 | 190 |
| Relief Valves (2) | 2,000 | 250 |
| Rupture Disks (2) | 1,100 | 1,130 |
| PROCESS MACHINERY: | | |
| Centrifugal Pump | 19,000 | 2,200 |
| INSTRUMENTATION: | | |
| Temperature Indicator | 2,200 | 260 |
| Pressure Gauges (6) | 2,200 | 260 |
| Flow Indicator | 3,700 | 430 |
| Load Cell | 16,000 | 1,800 |
| Remote Level Indicator | 1,900 | 220 |
| Level Alarm | 380 | 45 |
| High-Low Level Shutoff | 1,900 | 220 |
| ENCLOSURES: | | |
| Concrete Building | 19,000 | 2,200 |
| SCRUBBERS: | | |
| Alkaline Scrubber | 269,000 | 31,000 |
| DIKING: | | |
| 10 ft. High Concrete Dike | 7,600 | 880 |
| PROCEDURES AND PRACTICES: | | |
| Visual Tank Inspection (external) | | 15 |
| Visual Tank Inspection (internal) | | 60 |
| Relief Valve Inspection | | 50 |
| Piping Inspection | | 300 |
| Piping Maintenance | | 120 |
| Valve Inspection | | 35 |
| Valve Maintenance | | 400 |
| TOTAL COSTS | 532,000 | 63,000 |

TABLE 4-10. ESTIMATED TYPICAL CAPITAL AND ANNUAL COSTS ASSOCIATED WITH BASELINE CONTINUOUS CHLOROPICRIN PRODUCTION

| | Capital Cost (1986 $) | Annual Cost (1986 $/yr) |
|---|---|---|
| VESSELS: | | |
| Batch Reactor | 34,000 | 4,000 |
| PIPING AND VALVES: | | |
| Pipework | 6,900 | 830 |
| Ball and Globe Valves (4) | 2,200 | 260 |
| Relief Valve | 1,000 | 120 |
| PROCESS MACHINERY: | | |
| Centrifugal Pump | 5,200 | 620 |
| INSTRUMENTATION: | | |
| Pressure Gauges (3) | 1,100 | 130 |
| Flow Control Loops (2) | 11,000 | 1,300 |
| PROCEDURES AND PRACTICES: | | |
| Visual Tank Inspection (external) | | 15 |
| Visual Tank Inspection (internal) | | 60 |
| Relief Valve Inspection | | 15 |
| Piping Inspection | | 600 |
| Piping Maintenance | | 250 |
| Valve Inspection | | 40 |
| Valve Maintenance | | 400 |
| TOTAL COSTS | 62,000 | 9,000 |

TABLE 4-11. ESTIMATED TYPICAL CAPITAL AND ANNUAL COSTS ASSOCIATED WITH LEVEL 1 CONTINUOUS CHLOROPICRIN PRODUCTION

| | Capital Cost (1986 $) | Annual Cost (1986 $/yr) |
|---|---|---|
| VESSELS: | | |
| Batch Reactor | 52,000 | 6,300 |
| PIPING AND VALVES: | | |
| Pipework | 13,000 | 1,600 |
| Ball and Globe Valves (4) | 2,200 | 260 |
| Relief Valve | 1,000 | 120 |
| PROCESS MACHINERY: | | |
| Centrifugal Pump | 12,000 | 1,500 |
| INSTRUMENTATION: | | |
| Pressure Gauges (3) | 1,100 | 130 |
| Flow Indicator | 3,600 | 430 |
| Flow Control Loops (2) | 11,000 | 1,300 |
| Temperature Indicator | 2,200 | 260 |
| Temperature Alarm | 360 | 45 |
| Temperature Sensor | 360 | 45 |
| DIKING: | | |
| Curbing Around Reactor | 910 | 110 |
| ENCLOSURE: | | |
| Steel Building | 8,300 | 1,000 |
| SCRUBBER: | | |
| Alkaline Scrubber | 260,000 | 31,000 |
| PROCEDURES AND PRACTICES: | | |
| Visual Tank Inspection (external) | | 15 |
| Visual Tank Inspection (internal) | | 60 |
| Relief Valve Inspection | | 15 |
| Piping Inspection | | 600 |
| Piping Maintenance | | 250 |
| Valve Inspection | | 40 |
| Valve Maintenance | | 400 |
| TOTAL COSTS | 368,000 | 46,000 |

TABLE 4-12. ESTIMATED TYPICAL CAPITAL AND ANNUAL COSTS ASSOCIATED WITH LEVEL 2 CONTINUOUS CHLOROPICRIN MANUFACTURE

| | Capital Cost (1986 $) | Annual Cost (1986 $/yr) |
|---|---|---|
| VESSELS: | | |
| Storage Tank | 105,000 | 13,000 |
| PIPING AND VALVES: | | |
| Pipework | 29,000 | 3,500 |
| Ball and Globe Valves (4) | 1,700 | 260 |
| Relief Valve | 2,000 | 120 |
| PROCESS MACHINERY: | | |
| Centrifugal Pump | 19,000 | 2,200 |
| INSTRUMENTATION: | | |
| Pressure Gauges (4) | 1,500 | 170 |
| Flow Indicator | 3,600 | 430 |
| Flow Interlock System | 1,800 | 220 |
| Liquid Level Gauge | 1,500 | 170 |
| Remote Level Indicator | 1,800 | 220 |
| Level Alarm | 360 | 45 |
| Temperature Sensor | 360 | 45 |
| Temperature Switch | 540 | 65 |
| Temperature Alarm | 360 | 45 |
| Temperature Indicator | 1,800 | 220 |
| Mixing Interlock System | 1,800 | 220 |
| ENCLOSURES: | | |
| Concrete Building | 11,000 | 1,300 |
| SCRUBBER: | | |
| Alkaline Scrubber | 260,000 | 31,000 |
| DIKING: | | |
| 3 ft. Retaining Wall | 1,600 | 200 |
| PROCEDURES AND PRACTICES: | | |
| Visual Tank Inspection (external) | | 15 |
| Visual Tank Inspection (internal) | | 60 |
| Relief Valve Inspection | | 30 |
| Piping Inspection | | 300 |
| Piping Maintenance | | 120 |
| Valve Inspection | | 35 |
| Valve Maintenance | | 400 |
| TOTAL COSTS | 445,000 | 33,000 |

TABLE 4-13. EQUIPMENT SPECIFICATIONS ASSOCIATED WITH CHLOROPICRIN STORAGE SYSTEM

| Equipment Item | Equipment Specification | Reference |
|---|---|---|
| VESSELS: | | |
| Storage Tank | Baseline: 10,000 gallon carbon steel storage tank, 15 psig rating<br>Level #1: 10,000 gallon carbon steel with 1/8 inch corrosion protection, 25 psig<br>Level #2: 10,000 gallon Kynar®-lined carbon steel, 50 psig | 18,19,20, 15 |
| PIPING AND VALVES: | | |
| Pipework | Baseline: 100 ft. of 2 in. Schedule 40 carbon steel<br>Level #1: 2 in. schedule 80 carbon steel<br>Level #2: 2 in. schedule 80 Kynar®-lined carbon steel | 22 |
| Check Valve | 2 in. vertical lift check valve, carbon steel construction | 19,23 |
| Ball Valve | 2 in. Class 300, carbon steel body | 18,19,23 |
| Relief Valve | 1 in. x 2 in., Class 300 inlet and outlet flange, angle body, closed bonnet with screwed cap, carbon steel body | 19 |
| Reduced Pressure Device | Double check valve type device with internal air gap and relief valve | 18 |
| Rupture Disk | 1 in. Monel® disk and carbon steel holder | 18,20,24 |
| PROCESS MACHINERY: | | |
| Centrifugal Pump | Baseline: Single stage, carbon steel construction, stuffing box, 100 gpm capacity.<br>Level #1: Single stage, Kynar®-lined carbon steel construction, double mechanical seal<br>Level #2: Kynar®-lined carbon steel, mechanically-coupled | 19,25<br><br>19,25 |

(Continued)

TABLE 4-13 (Continued)

| Equipment Item | Equipment Specification | Reference |
|---|---|---|
| INSTRUMENTATION: | | |
| Temperature Indicator | Thermocouple, thermowell, electronic indicator | 18,19,26 |
| Pressure Gauge | Diaphragm sealed, Hastelloy C diaphragm, 0-1,000 psi | 18,19,26 |
| Flow Indicator | Differential pressure cell and transmitter, associated meter | |
| Level Indicator | Differential pressure type indicator | 18,26 |
| Load Cell | Electronic load cell | 18,26,27 |
| Level Alarm | Indicating and audible alarm | 19,28,29 |
| High-Low Level Shutoff | Solenoid valve, switch, and relay system | 18,19,26 28 |
| ENCLOSURES: | | |
| Building | Level #1: 26-gauge steel walls and roof, door, ventilation system<br>Level #2: 10 in. concrete walls, 26-gauge steel roof | 28 |
| SCRUBBERS: | Level #1 & 2: Spray tower, Monel® construction, alkaline sprays, 4 ft. x 12 ft. | 30 |
| DIKING: | Level #1: 6 in. concrete walls 3 ft. high<br>Level #2: 10 in. concrete walls, top of tank height | 28 |

TABLE 4-14. MATERIAL AND LABOR COSTS ASSOCIATED WITH BASELINE CHLOROPICRIN STORAGE SYSTEM

| | Materials Cost | Labor Cost | Direct Costs | Indirect Costs | Capital Costs |
|---|---|---|---|---|---|
| | | | (1986 $) | | |
| VESSELS: | | | | | |
| Storage Tank | 12,000 | 5,400 | 17,400 | 6,100 | 26,000 |
| PIPING AND VALVES: | | | | | |
| Pipework | 600 | 1,400 | 2,000 | 700 | 3000 |
| Check Valves | 160 | 30 | 190 | 70 | 290 |
| Ball Valves (5) | 1,000 | 150 | 1,150 | 400 | 1,700 |
| Relief Valve | 650 | 50 | 700 | 250 | 1,000 |
| PROCESS MACHINERY: | | | | | |
| Centrifugal Pump | 1,500 | 1,100 | 3,600 | 1,300 | 5,400 |
| INSTRUMENTATION: | | | | | |
| Pressure Gauges (4) | 800 | 200 | 1,000 | 350 | 1,500 |
| Liquid Level Gauge | 800 | 200 | 1,000 | 350 | 1,500 |
| TOTAL COSTS | 18,000 | 9,000 | 27,000 | 9,500 | 40,000 |

TABLE 4-15. MATERIAL AND LABOR COSTS ASSOCIATED WITH LEVEL 1 CHLOROPICRIN STORAGE SYSTEM

| | Materials Cost | Labor Cost | Direct Costs | Indirect Costs | Capital Costs |
|---|---|---|---|---|---|
| | | | (1986 $) | | |
| VESSELS: | | | | | |
| Storage Tank | 25,000 | 11,000 | 36,000 | 13,000 | 53,000 |
| PIPING AND VALVES: | | | | | |
| Pipework | 1,000 | 2,000 | 3,000 | 1,000 | 4,000 |
| Check Valves | 320 | 60 | 380 | 130 | 560 |
| Ball Valves (5) | 1,000 | 150 | 1,150 | 400 | 1,700 |
| Relief Valves (2) | 1,300 | 100 | 1,400 | 500 | 2,000 |
| PROCESS MACHINERY: | | | | | |
| Centrifugal Pump | 6,000 | 2,600 | 8,600 | 3,000 | 13,000 |
| INSTRUMENTATION: | | | | | |
| Pressure Gauges (4) | 800 | 200 | 1,000 | 350 | 1,500 |
| Flow Indicator | 2,000 | 500 | 2,500 | 880 | 3,700 |
| Liquid Level Gauge | 800 | 200 | 1,000 | 350 | 1,500 |
| Remote Level Indicator | 1,000 | 250 | 1,250 | 440 | 1,900 |
| ENCLOSURES | | | | | |
| Steel Building | 4,600 | 2,300 | 6,900 | 2,400 | 10,000 |
| SCRUBBER: | | | | | |
| Alkaline Scrubber | 125,000 | 56,000 | 181,000 | 63,000 | 269,000 |
| DIKING: | | | | | |
| 3 ft. High Concrete Diking | 390 | 510 | 900 | 320 | 1,300 |
| TOTAL COSTS | 170,000 | 76,000 | 245,000 | 86,000 | 363,000 |

TABLE 4-16. MATERIAL AND LABOR COSTS ASSOCIATED WITH LEVEL 2 CHLOROPICRIN STORAGE SYSTEM

| | Materials Cost | Labor Cost | Direct Costs | Indirect Costs | Capital Costs |
|---|---|---|---|---|---|
| | | | (1986 $) | | |
| VESSELS: | | | | | |
| Storage Tank | 80,000 | 36,000 | 116,000 | 41,000 | 173,000 |
| PIPING AND VALVES: | | | | | |
| Pipework | 4,000 | 2,600 | 6,600 | 2,300 | 10,000 |
| Reduced Pressure Device | 800 | 200 | 1,000 | 350 | 1,500 |
| Ball Valves (5) | 1,000 | 150 | 1,150 | 400 | 1,700 |
| Relief Valves (2) | 1,300 | 100 | 1,400 | 500 | 2,000 |
| Rupture Disks (2) | 650 | 75 | 725 | 260 | 1,100 |
| PROCESS MACHINERY: | | | | | |
| Centrifugal Pump | 9,000 | 3,900 | 12,900 | 4,500 | 19,000 |
| INSTRUMENTATION: | | | | | |
| Temperature Indicator | 1,200 | 300 | 1,500 | 530 | 2,200 |
| Pressure Gauges (6) | 1,200 | 300 | 1,500 | 530 | 2,200 |
| Flow Indicator | 2,000 | 500 | 2,500 | 880 | 3,700 |
| Load Cell | 8,400 | 2,100 | 10,500 | 3,700 | 16,000 |
| Remote Level Indicator | 1,000 | 250 | 1,250 | 440 | 1,900 |
| Level Alarm | 200 | 50 | 250 | 90 | 380 |
| High-Low Level Shutoff | 1,000 | 250 | 1,250 | 440 | 1,900 |
| ENCLOSURES | | | | | |
| Concrete Building | 6,100 | 6,600 | 12,700 | 4,400 | 19,000 |
| SCRUBBERS: | | | | | |
| Alkaline Scrubber | 125,000 | 56,000 | 181,000 | 63,000 | 269,000 |
| DIKING: | | | | | |
| 10 ft. High Concrete Dike | 2,200 | 2,900 | 5,100 | 1,800 | 7,600 |
| TOTAL COSTS | 245,000 | 112,000 | 357,000 | 125,000 | 532,000 |

TABLE 4-17. EQUIPMENT SPECIFICATIONS ASSOCIATED WITH CHLOROPICRIN MANUFACTURE

| Equipment Item | Equipment Specification | Reference |
|---|---|---|
| VESSELS: | | |
| Reactor | 2,000 gallon batch reactor | 18,19 |
| PIPING AND VALVES: | | |
| Pipework | Baseline: Schedule 40 CPVC for bleach solution, Schedule 40 carbon steel for chloropicrin<br>Level #1: Schedule 80 carbon steel<br>Level #2: Schedule 80 Kynar®-lined carbon steel | 22 |
| Ball valves | 2 in. Class 300, carbon steel body | 18,19,23 |
| Globe valves | 2 in. Class 300, cast steel | 18,19,23 |
| Relief valve | 1 in. x 2 in., Class 300 inlet and outlet flange, angle body, closed bonnet with screwed cap, carbon steel body | 19 |
| Rupture disk | 1 in. Monel® disk and carbon steel steel holder | 18,20,24 |
| PROCESS MACHINERY: | | |
| Centrifugal pump | Baseline: Single stage, carbon steel construction, stuffing box, 100 gpm capacity | |
| | Level #1: Single stage, Kynar®-lined construction, double mechanical seal | 19,25 |
| | Level #2: Kynar®-lined, magnetically-coupled | 19,25 |
| INSTRUMENTATION: | | |
| Level alarm | Indicating and audible alarm | 19,28,29 |
| Interlock system | Solenoid valve, switch, and relay system | 18,19,26<br>28 |
| Pressure gauge | Diaphragm sealed, Hastelloy C diaphragm, 0-1,000 psi | 18,19,26 |
| Flow control loop | 2 in. Globe control valve, flowmeter and PID controller | 18,26 |
| Temperature indicator | Thermocouple, thermowell, and electronic indicator | 18,19,26 |
| Temperature sensor | Thermocouple and associated thermowell | 18,19,26 |

(Continued)

TABLE 4-17 (Continued)

| Equipment Item | Equipment Specification | Reference |
|---|---|---|
| DIKING: | Level #1: 6 in. high concrete curing<br>Level #2: 3 ft. high concrete retaining wall | 28 |
| ENCLOSURE: | Level #1: 26 gauge steel walls and roof, door, ventilation system<br>Level #2: 10 in. concrete walls, 26 gauge steel roof, door | 28 |
| SCRUBBER: | Level #1&2: Spray tower, Monel® construction, alkaline sprays, 4 ft. x 12 ft. | 30 |

TABLE 4-18. MATERIAL AND LABOR COSTS ASSOCIATED WITH BASELINE CONTINUOUS CHLOROPICRIN PRODUCTION

| | Materials Cost | Labor Cost | Direct Costs | Indirect Costs | Capital Costs |
|---|---|---|---|---|---|
| | | | (1986 $) | | |
| VESSELS: | | | | | |
| Batch Reactor | 16,000 | 7,400 | 23,400 | 5,900 | 34,000 |
| PIPING AND VALVES: | | | | | |
| Pipework | 1,800 | 3,000 | 4,800 | 1,200 | 6,900 |
| Ball and Globe Valves (4) | 1,000 | 500 | 1,500 | 380 | 2,200 |
| Relief Valve | 650 | 50 | 700 | 180 | 1,000 |
| PROCESS MACHINERY: | | | | | |
| Centrifugal Pump | 2,500 | 1,100 | 3,600 | 900 | 5,200 |
| INSTRUMENTATION: | | | | | |
| Pressure Gauges (3) | 600 | 150 | 750 | 190 | 1,100 |
| Flow Control Loops (2) | 6,000 | 1,500 | 7,500 | 1,900 | 11,000 |
| TOTAL COSTS | 29,000 | 14,000 | 43,000 | 11,000 | 62,000 |

TABLE 4-19. MATERIAL AND LABOR COSTS ASSOCIATED WITH LEVEL 1 CONTINUOUS CHLOROPICRIN PRODUCTION

| | Materials Cost | Labor Cost | Direct Costs | Indirect Costs | Capital Costs |
|---|---|---|---|---|---|
| | | | (1986 $) | | |
| VESSELS: | | | | | |
| Batch Reactor | 25,000 | 11,000 | 36,000 | 9,000 | 52,000 |
| PIPING AND VALVES: | | | | | |
| Pipework | 3,000 | 6,000 | 9,000 | 2,300 | 13,000 |
| Ball and Globe Valves (4) | 1,000 | 500 | 1,500 | 380 | 2,200 |
| Relief Valve | 650 | 50 | 700 | 180 | 1,000 |
| PROCESS MACHINERY: | | | | | |
| Centrifugal Pump | 6,000 | 2,600 | 8,600 | 2,200 | 12,000 |
| INSTRUMENTATION: | | | | | |
| Pressure Gauges (3) | 600 | 150 | 750 | 190 | 1,100 |
| Flow Indicator | 2,000 | 500 | 2,500 | 630 | 3,600 |
| Flow Control Loops (2) | 6,000 | 1,500 | 7,500 | 1,900 | 11,000 |
| Temperature Indicator | 1,200 | 300 | 1,500 | 380 | 2,200 |
| Temperature Alarm | 200 | 50 | 250 | 60 | 360 |
| Temperature Sensor | 200 | 50 | 250 | 60 | 360 |
| DIKING: | | | | | |
| Curbing Around Reactor | 500 | 130 | 630 | 160 | 910 |
| ENCLOSURE: | | | | | |
| Steel Building | 4,600 | 1,200 | 5,800 | 1,500 | 8,300 |
| SCRUBBER: | | | | | |
| Alkaline Scrubber | 125,000 | 56,000 | 181,000 | 45,000 | 260,000 |
| TOTAL COSTS | 176,000 | 80,000 | 256,000 | 64,000 | 368,000 |

TABLE 4-20. MATERIAL AND LABOR COSTS ASSOCIATED WITH LEVEL 2 CONTINUOUS CHLOROPICRIN PRODUCTION

| | Materials Cost | Labor Cost | Direct Costs | Indirect Costs | Capital Costs |
|---|---|---|---|---|---|
| | | | (1986 $) | | |
| VESSELS: | | | | | |
| Storage Tank | 50,000 | 23,000 | 73,000 | 18,000 | 105,000 |
| PIPING AND VALVES: | | | | | |
| Pipework | 12,000 | 8,000 | 20,000 | 5,000 | 29,000 |
| Ball and Globe Valves (4) | 1,000 | 150 | 1,150 | 290 | 1,700 |
| Relief Valve | 1,300 | 100 | 1,400 | 350 | 2,000 |
| PROCESS MACHINERY: | | | | | |
| Centrifugal Pump | 9,000 | 3,900 | 12,900 | 3,200 | 19,000 |
| INSTRUMENTATION: | | | | | |
| Pressure Gauges (4) | 800 | 200 | 1,000 | 250 | 1,500 |
| Flow Indicator | 2,000 | 500 | 2,500 | 880 | 3,600 |
| Flow Interlock System | 1,000 | 250 | 1,250 | 310 | 1,800 |
| Liquid Level Gauge | 800 | 200 | 1,000 | 250 | 1,500 |
| Remote Level Indicator | 1,000 | 250 | 1,250 | 310 | 1,800 |
| Level Alarm | 200 | 50 | 250 | 60 | 360 |
| Temperature Sensor | 200 | 50 | 250 | 60 | 360 |
| Temperature Switch | 300 | 75 | 375 | 95 | 540 |
| Temperature Alarm | 200 | 50 | 250 | 60 | 360 |
| Temperature Indicator | 1,000 | 250 | 1,250 | 310 | 1,800 |
| Mixing Interlock System | 1,000 | 250 | 1,250 | 310 | 1,800 |
| ENCLOSURES: | | | | | |
| Concrete Building | 6,100 | 1,500 | 7,600 | 1,900 | 11,000 |
| SCRUBBER: | | | | | |
| Alkaline Scrubber | 125,000 | 56,000 | 181,000 | 45,000 | 260,000 |
| DIKING: | | | | | |
| 3 ft. Retaining Wall | 900 | 230 | 1,130 | 290 | 1,600 |
| TOTAL COSTS | 214,000 | 95,000 | 309,000 | 77,000 | 445,000 |

TABLE 4-21. FORMAT FOR TOTAL FIXED CAPITAL COST

| Item No. | Item | Cost |
|---|---|---|
| 1 | Total Material Cost | - |
| 2 | Total Labor Cost | - |
| 3 | Total Direct Cost | Items 1 + 2 |
| 4 | Indirect Cost Items (Engineering & Construction Expenses) | 0.35 x Item 3[a] |
| 5 | Total Bare Module Cost | Items (3 + 4) |
| 6 | Contingency | (0.05 x Item 5)[b] |
| 7 | Contractor's Fee | 0.05 x Item 5 |
| 8 | Total Fixed Capital Cost | Items (5 + 6 + 7) |

[a]For storage facilities, the indirect cost factor is 0.35. For process facilities, the indirect cost factor is 0.25.

[b]For storage facilities, the contingency cost factor is 0.05. For process facilities, the contingency cost factor is 0.10.

The first group of other cost elements is direct costs. These include engineering and supervision, construction expenses, and various other expenses, such as administration expenses. These costs are computed by multiplying total direct costs by a factor shown in Table 4-21. The factor is approximate, is obtained from the cost literature, and is based on previous experience with capital projects of a similar nature. Factors can have a range of values and vary according to technology area and individual technologies within an area. Appropriate factors based on judgement and experience were selected for this report.

When the indirect costs are added to the total direct costs, total bare module cost is obtained. Some additional cost elements, such as contractor's fee and contingency, are calculated by applying and adding appropriate factors to the total bare module cost, as shown in Table 4-21, to obtain the total fixed capital cost.

Annual Cost--Annual costs are obtained for each equipment item by applying a factor for both capital recovery and for maintenance expenses to the direct cost of each equipment item. Table 4-22 defines the cost elements and the appropriate factors comprising these costs. Additional annual costs are incurred for procedural items such as valve and vessel inspections, for example. The sum of these individual costs equals the total annual cost.

Source of Information--

Costs presented in this report are derived from cost information in existing published sources and also from recent vendor information. The objective of this effort was to present cost levels for chloropicrin process and storage facilities using the best costs for available sources. The primary sources of cost information are Peters and Timmerhaus (18), Chemical Engineering (31), and Valle-Riestra (32), supplemented by other sources and references where necessary. Adjustments were made to update all costs to a June 1986 dollar basis. For some equipment items, well-documented costs were not available and they had to be developed from component costs.

TABLE 4-22. FORMAT FOR TOTAL ANNUAL COST

| Item No. | Item | Cost |
|---|---|---|
| 1 | Total Direct Cost | - |
| 2 | Capital Recovery on Equipment Items | 0.163 x Item 1 |
| 3 | Maintenance Expense on Equipment Items | 0.01 x Item 1 |
| 4 | Total Procedural Items | - |
| 5 | Total Annual Cost | Items (2 + 3 + 4) |

Costs in this document reflect the "typical" or "average" representation for specific equipment items. This restricts the use of data in this report to:

- Preliminary estimates used for policy planning;
- Comparison of relative costs of different levels or systems; and
- Approximations of costs that might be incurred for a specific application.

The costs in this report are considered to be "order of magnitude" with a ±50 percent margin because costs are based on preliminary estimates and many are updated from literature sources. Large departures from the design basis of a particular system presented in this manual or the advent of a different technology might cause the system cost to vary more than this. If used as intended, however, this document will provide a reasonable source of preliminary cost information for the facilities covered.

When comparing costs in this manual to those from other references, the user should be sure the design bases are comparable and that the capital and annual costs as defined here are the same.

Cost Updating--

All costs in this report are expressed in June 1986 dollars. Costs reported in the literature were updated using cost indices for materials and labor.

Costs expressed in base-year dollars may be adjusted to dollars for another year by applying cost indices as shown in the following equation:

$$\text{new base-year cost} = \text{old base-year cost} \times \frac{\text{new base year index}}{\text{old base year index}}$$

The chemical Engineering (CE) Plant Cost Index was used in updating cost for this report. For June 1986, the index is 316.3.

Equipment Costs--

Most of the equipment costs presented in this manual were obtained directly from literature sources of vendor information and correspond to a specific design standard. Special cost estimating techniques, however, were used in determining the costs associated with vessels, piping systems, scrubbers, diking, and enclosures. The techniques used are presented in the following subsections of this manual.

Vessels--The total purchased cost for a vessel, as dollars per pound of weight of fabricated unit free on board (f.o.b.) with carbon steel as the basis (January 1979 dollars) were determined using the following equation from Peters and Timmerhaus (18):

$$\text{Cost} = [50(\text{Weight of Vessel in Pounds})^{-0.34}]\ [\text{Weight of Vessel in Pounds}]$$

The vessel weight is determined using appropriate design equations as given by Peters and Timmerhaus (18) that allow for wall thickness adjustments for corrosion allowances, for example. The vessel weight is increased by a factor of 0.15 for horizontal vessels and 0.20 for vertical vessels to account for the added weight of nozzles, manholes, and skirts or saddles. Appropriate factors are applied for different construction materials, as given in Peters and Timmerhaus (18). Vessel costs are updated using cost factors. Finally, a shipping cost amounting to 10 percent of the purchased cost is added to obtain the delivered equipment cost.

Piping--Piping costs were obtained using cost information and data presented by Yamartino (22). A simplified approach is used in which it is assumed that a certain length of piping containing a given number of valves, flanges, and fittings is contained in the storage or process facility. The data presented by Yamartino (22) permit cost determinations for various

lengths, sizes, and types of piping systems. Using these factors, a representative estimate can be obtained for each of the storage and process facilities.

Diking--Diking costs were estimated using Mean's Manual (28) for reinforced concrete walls. The following assumptions were made to determine the costs. The dike contains the entire contents of a tank in the event of a leak or release. Two dike sizes are possible: a three-foot high dike, six-inches thick and a top-of-tank height dike ten inches thick. The tanks are raised off the ground and are not volumetrically included in the volume enclosed by the diking. These assumptions facilitate cost determination for any size diking system.

Enclosures--Enclosure costs were estimated using Mean's Manual (28) for both reinforced concrete and steel-walled buildings. The buildings are assumed to enclose the same area and volume as the top-of-tank height dikes. The concrete building is ten-inches thick with a 26-gauge steel roof and a metal door. The steel building has 26 gauge roofing and siding and metal door. The cost of a ventilation system was determined using a typical 1,000 scfm unit and doubling the cost to account for duct work and requirements for the safe enclosure of hazardous chemicals.

Scrubbers--Scrubber costs were estimated by the following equation from the Gard (30) manual for spray towers based on the actual cubic feet per minute of flow at a chamber velocity of 600 feet/minute.

$$\text{Costs} = 0.235 \times (\text{ACFM} + 43{,}000)$$

A release rate of 1,000 $ft^3$/minute was assumed for the storage vessel systems and an appropriate rate was determined for process system based on the quantity of hazardous chemicals present in the system at any one time. For the chloropicrin reactor system, a release rate of 1,000 $ft^3$/minute was assumed. In addition to the spray tower, the costs also include pumps and a storage

tank for the scrubbing medium. The costs presented are updated to June 1986 dollars.

Installation Factors--

Installation costs were developed for all equipment items included in both the process and storage systems. The costs include both the material and labor costs for installation of a particular piece of equipment. Costs were obtained directly from literature sources and vendor information or indirectly by assuming a certain percentage of the purchased equipment cost by using estimating factors obtained from Peters and Timmerhaus (18) and Valle-Riestra (32). Table 4-23 lists the cost factors used or the reference from which the cost was obtained directly. Many of the costs obtained from the literature were updated to June 1986 dollars using a 10 percent per year rate of increase for labor and cost indices for materials associated with installation.

TABLE 4-23. FORMAT FOR INSTALLATION COSTS

| Equipment Item | Factor or Reference |
|---|---|
| Vessels: | |
| Storage Tank | 0.45 |
| Piping and Valves: | |
| Pipework | Ref. 22 |
| Reduced Pressure Device | Ref. 19 |
| Check Valves | Ref. 19 |
| Gates Valves | Ref. 19 |
| Ball Valves | Ref. 19 |
| Relief Valves | Ref. 19 |
| Rupture Disks | Ref. 19 |
| Process Machinery: | |
| Centrifugal Pump | 0.43 |
| Gear Pump | 0.43 |
| Instrumentation: | |
| All Instrumentation Items | 0.25 |
| Enclosures: | Ref. 28 |
| Diking: | Ref. 28 |
| Scrubbers: | 0.45 |

## SECTION 5
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# APPENDIX A
# GLOSSARY

This glossary defines selected terms used in the text of this manual which might be unfamiliar to some users or which might be used differently by different authors.

Accidental release: The unintentional spilling, leaking, pumping, purging, emitting, emptying, discharging, escaping, dumping, or disposing of a toxic material into the environment in a manner that is not in compliance with a plant's federal, state, or local environmental permits and/or results in toxic concentrations in the air that are a potential health threat to the surrounding community.

Assessment: The process whereby the hazards which have been identified are evaluated in order to provide an estimate for the level of risk.

Cavitation: The formation and collapse of vapor bubbles in a flowing liquid. Specifically, the formation and collapse of vapor cavities in a pump when there is sufficient resistance to flow at the inlet side.

Containment/control: A system to which toxic emissions from safety relief discharges are routed to be controlled. A caustic scrubber and/or flare can be containment/control devices. These systems may serve the dual function of destructing continuous process exhaust gas emissions.

Creep failure: Failure of a piece of metal as a result of creep. Creep is time dependent deformation as a result of stress. Metals will deform when exposed to stress. High levels of stress can result in rapid deformation and rapid failure. Lower levels of stress can result in slow deformation and protracted failure.

Deadheading: Closing or nearly closing or blocking the discharge outlet or piping of an operating pump or compressor.

Facility: A location at which a process or set of processes are used to produce, refine or repackage chemicals, or a location where a large enough inventory of chemicals are stored so that a significant accidental release of a toxic chemical is possible.

Hazard: A source of danger. The potential for death, injury or other forms of damage to life and property.

Hygroscopic: Readily absorbing and retaining moisture, usually in reference to readily absorbing moisture from the air.

Identification: The recognition of a situation, its causes and consequences relating to a defined potential, e.g., Hazard Identification.

Mild steel: Carbon steel containing a maximum of about 0.25% carbon. Mild steel is satisfactory for use where severe corrodants are not encountered or where protective coatings can be used to prevent or reduce corrosion rates to acceptable levels.

Mitigation: Any measure taken to reduce the severity of the adverse effects associated with the accidental release of a hazardous chemical.

Passivation film: A layer of oxide or other chemical compound of a metal on its surface that acts as a protective barrier against corrosion or further chemical reaction.

Plant: A location at which a process or set of processes are used to produce, refine or repackage chemicals.

Prevention: Design and operating measures applied to a process to ensure that primary containment of toxic chemicals is maintained. Primary containment means confinement of toxic chemicals within the equipment intended for normal operating conditions.

Primary Containment: The containment provided by the piping, vessels and machinery used in a facility for handling chemicals under normal operating conditions.

Probability/potential: A measure, either qualitative or quantitative, that an event will occur within some unit of time.

Process: The sequence of physical and chemical operations for the production, refining, repackaging, or storage of chemicals.

Process machinery: Process equipment, such as pumps, compressors, heaters, or agitators that would not be categorized as piping or vessels.

Protection: Measures taken to capture or destroy a toxic chemical that has breached primary containment, but before an uncontrolled release to the environment has occurred.

Qualitative Evaluation: Assessing the risk of an accidental release at a facility in relative terms; the end result of the assessment being a verbal description of the risk.

Quantitative Evaluation: Assessing the risk of an accidental release at a facility in numerical terms; the end result of the assessment being some type of number reflects risk, such as faults per year or mean time between failure.

Reactivity: The ability of one chemical to undergo a chemical reaction with another chemical. Reactivity of one chemical is always measured in reference to the potential for reaction with itself or with another chemical. A

chemical is sometimes said to be "reactive," or have high "reactivity," without reference to another chemical. Usually this means that the chemical has the ability to react with common materials such as water, or common materials of construction such as carbon steel.

Redundancy: For control systems, redundancy is the presence of a second piece of control equipment where only one would be required. The second piece of equipment is installed to act as a backup in the event that the primary piece of equipment fails. Redundant equipment can be installed to backup all or selected portions of a control system.

Risk: The probability that a hazard may be realized at any specified level in a given span of time.

Secondary Containment: Process equipment specifically designed to contain material that has breached primary containment before the material is released to the environment and becomes an accidental release. A vent duct and scrubber that are attached to the outlet of a pressure relief device are examples of secondary containment.

Toxicity: A measure of the adverse health effects of exposure to a chemical.

APPENDIX B

TABLE B-1. METRIC (SI) CONVERSION FACTORS

| Quantity | To Convert From | To | Multiply By |
|---|---|---|---|
| Length: | in | cm | 2.54 |
| | ft | m | 0.3048 |
| Area: | $in^2$ | $cm^2$ | 6.4516 |
| | $ft^2$ | $m^2$ | 0.0929 |
| Volume: | $in^3$ | $cm^3$ | 16.39 |
| | $ft^3$ | $m^3$ | 0.0283 |
| | gal | $m^3$ | 0.0038 |
| Mass (weight): | lb | kg | 0.4536 |
| | short ton (ton) | Mg | 0.9072 |
| | short ton (ton) | metric ton (t) | 0.9072 |
| Pressure: | atm | kPa | 101.3 |
| | mm Hg | kPa | 0.133 |
| | psia | kPa | 6.895 |
| | psig | kPa* | (psig +14.696)x(6.895) |
| Temperature: | °F | °C* | (5/9)x(°F-32) |
| | °C | K* | °C+273.15 |
| Caloric Value; | Btu/lb | kJ/kg | 2.326 |
| Enthalpy: | Btu/lbmol | kJ/kgmol | 2.326 |
| | kcal/gmol | kJ/kgmol | 4.184 |
| Specific-Heat Capacity: | Btu/lb-°F | kJ/kg-°C | 4.1868 |
| Density: | $lb/ft^3$ | $kg/m^3$ | 16.02 |
| | lb/gal | $kg/m^3$ | 119.8 |
| Concentration: | oz/gal | $kg/m^3$ | |
| | quarts/gal | $cm^3/m^3$ | 25,000 |
| Flowrate: | gal/min | $m^3$/min | 0.0038 |
| | gal/day | $m^3$/day | 0.0038 |
| | $ft^3$/min | $m^3$/min | 0.0283 |
| Velocity: | ft/min | m/min | 0.3048 |
| | ft/sec | m/sec | 0.3048 |
| Viscosity: | centipoise (CP) | kg/m-s | 0.001 |

*Calculate as indicated